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**Smart Systems for Logistics
Command and Control (SSLC2)
Spiral Three**

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ABSTRACT

Smart Systems for Logistics Command and Control (SSLC2) is an Air Force Research Laboratory Warfighter Readiness Research Division program to develop and apply technologies to collect the critical information required to effectively manage logistics resources in support of combat operations. The purpose of SSLC2 is to develop capability requirements that employ technologies and techniques to autonomously collect and fuse critical data in order to create decision quality information and effectively present information to support cognitive tasks performed by logistics and operations decision-makers.

SSLC2 provides support to Expeditors and Production Supervisors (ProSupers) on the flightline. Spiral Three research focused on the fusion of information and presentation of the information through interactive visualizations to support situation awareness, decision making and collaboration when Expeditors and ProSupers are faced with multiple complex tasks and decisions. A user-centered design approach was used to support the development of visualizations. A cluster analysis technique was incorporated to determine how to integrate large amounts of data for arrangement in the interactive visualizations. A simulation test bed was created to allow Expeditors and ProSupers to evaluate SSLC2 concepts and provide their opinions on the effectiveness of information integration, visualizations, support for situation awareness, decision making, collaboration, resource visibility and resource allocation. A field demonstration was conducted at the Toledo Air National Guard which included 1) an interactive simulation that integrated flightline data with smart sensors that provided resource location and status and 2) a demonstration of live tags on the flightline. The simulated study collected user opinions via a questionnaire and comfort ratings, and timing results for situation awareness probe questions. The study results indicated that overall subjects found the SSLC2 system to be effective and useful. Many issues reported by subjects were related to SSLC2 requirements that have not been demonstrated but were already considered within the design. This report summarizes recommendations related to smart sensors, user interface, portability, trend analysis, flightline performance metrics, collaboration, configuration tracking, automation, integration with existing systems, resource conflict checking, and safety driven tasks. Future research needs and research contributions are

also described. The SSLC2 program demonstrated that commercial off-the-shelf (COTS) applications designed without thought to integration with existing systems where information may not be ideal can potentially cause problems or even rejection of the sensing technology. Integration of information is a key to the successful use of sensing technologies.

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1 Summary

Smart Systems for Logistics Command and Control (SSLC2) is an Air Force Research Laboratory Logistics Readiness Branch (AFRL/RHAL) Warfighter Readiness Research Division program to research, develop and apply technologies to collect the critical information required to effectively manage logistics resources in support of combat operations.

SSLC2 developed recommendations and requirements to transition concepts to existing Air Force systems. The research focused on ways to support logistic decision makers in complex flightline operations through the fusion of existing flightline information with smart sensor information. Specifically, Radio Frequency Identification / Real Time Location Systems (RFID/RTLS), information was presented through the use of interactive visualizations. The SSLC2 program was divided into three spirals. This report focuses on the research conducted during Spiral Three. The Spiral Three team consisted of MacAulay Brown, HumanWise, Inc., and Alion Science and Technology, Inc.

The goal of SSLC2 Spiral 3 was to investigate ways to support logistic decision makers in complex flightline operations through the fusion of existing flightline information with smart sensor information. The focus was on providing support to Expeditors and Production Supervisors (ProSupers) on the flightline. This research focused on the fusion of information and presentation of the information through interactive visualizations to support situation awareness, decision making and collaboration. The following five research objectives were met:

- Objective 1: Develop smart sensors for logistics operations.
- Objective 2: Develop a method for determining how data should be fused for presentation that focuses on supporting decisions and collaboration.
- Objective 3: Obtain user opinions of deployed sensors in the field.
- Objective 4: Develop a simulation test bed and evaluate user feedback on integrated data fusion decision support concepts.
- Objective 5: Develop recommendations for transition to existing systems.

The program started with information gathered from previous spirals which provided cognitive work models of the Expeditor and ProSuper and other system and user requirements. A user-centered approach was used to develop interactive visualizations which were programmed into a simulation test bed that fused information from RFID tags as well as simulated smart sensors with flightline information [5][7]. A method was created to support how data should be fused for presentation. A rating scale was developed to allow Subject Matter Experts (SMEs) to rate the importance of specific data to decisions. A cluster analysis was performed on the ratings. The information from the cognitive work analysis (CWA) and results of the cluster analysis were used to design interactive visualization concepts. The concepts were then presented to SMEs who provided feedback and indicated that the design concepts appeared useful and effective. Based upon the design concepts a detailed design was developed into a simulation test bed. Upon completion of the test bed, a study was conducted to obtain user opinions using the simulation test bed at the 180th FW Toledo Air National Guard at Toledo Express Airport, Swanton, OH in Swanton, Ohio (to be hereby referred to as Toledo ANG). A live sensor tag demonstration occurred concurrently.

The simulation included information related to 17 aircraft with sorties and maintenance for a one week (5 day) period. Five subjects interacted with the system using a tablet PC with a mouse and keyboard to solve problems, collaborate with other personnel, assign resources, make maintenance fix/swap decisions, and oversee scheduled and unscheduled maintenance. The study took approximately one and one-half hours to complete per subject. Subjects filled out a questionnaire to provide their feedback. During the simulation subjects were asked situational awareness questions related to information on the flightline and the time it took to answer was recorded. Subjects were also asked to indicate how comfortable they felt with the system as time progressed.

The feedback received from subjects and others who viewed the live demonstration was very positive. The questionnaire results indicated that subjects considered SSLC2 concepts and fusion of information from sensors with flightline data to be effective and useful and thought SSLC2 would help support situation awareness, decision making, and collaboration. Users indicated that this system would be ideal for current deployed

operations where they have been having difficulty finding all of their resources. The lead ProSuper at Toledo ANG indicated that it takes 15 minutes to collect the information needed to make a decision about whether or not an aircraft will meet a sortie. With this system he stated that they could make that decision in seconds. He also stated the system could reduce the time to make decisions and assign resources to maintenance tasks by up to 60%.

This program successfully developed recommendations for future spirals as well as requirements for transition to current Air Force systems. The implementation of this technology would help the Air Force towards its goal of becoming more agile.

1.1 RESEARCH PUBLICATION ACCOMPLISHMENTS

Throughout the SSLC2 research project we have published our findings and presented papers and posters to scientific peers. The papers and posters are listed below.

- Gallimore, J.J., Maki A., Faas, P., Seyba, J., Quill, L., and Matthews, E. (2005). The Need For A Human-in-the Loop Simulation Testbed for Logistics Decision Support Research. In *Proceedings of the Summer Simulation Conference*, 84-89.
- “How Can We Make Logistics Command & Control Technologies Smart”; Integrated System Health Management Conference Poster; 9-11 August 2005.
- “Smart Systems for Logistics Command and Control”; National Annual Society for Logistics Engineers Conference; 16-18 August 2005.
- “Virtual Space Logistics Readiness Center”; National Annual Society for Logistics Engineers Conference; 16-18 August 2005.
- Faas, P., Seyba, J., Young, I., Gallimore, J.J., Quill, L., Matthews, E., and Cagle, R. (2006). Collaborative Logistics on the Military Flightline. International Symposium on Collaborative Technologies and Systems (CTS'06), 215-219.
- Gallimore, J.J., Quill, L., Cagle, R., Gruenke, J., Hosman, C., Matthews, E., Faas, P., Seyba, J. and Young, I. (2006). User Feedback on RFID and Integrated Flightline Data for Maintenance Decisions. In *Proceedings of the Institute of Industrial Engineers Annual Conference*. May, Orlando. CDROM.
- “Smart Systems for Logistics Command and Control”, Integrated System Health Management Conference Poster; 14-17 August 2006.

- Gallimore, J.J. Matthews, E.M., Cagle, R. Faas, P., Seyba, J. and Whited, V. (In Press). Integrating Sensor Data with System Information Via Interactive Visualizations. In *Proceedings of the 2007 International Human Computer Interaction Conference*, July 23-28, 2007, Beijing, China.
- GRACAR Corporation (2006). Smart Systems for Logistics Command and Control (SSLC2): Interim Final Report, Spiral 1. Contract Number FA8650-04-C-6404. Dayton, OH.
- GRACAR Corporation (2006). Smart Systems for Logistics Command and Control (SSLC2): Interim Final Report, Spiral 2. Contract Number FA8650-04-C-6404. Dayton, OH.

2 Introduction

Logistics support for the U.S. Military is a complex, time dependent, yet critical task. Creating Agile Combat Support (ACS) for the warfighter requires real time integrated information systems to support human decision making. Through the years, support tools have been created to support logistics problems. Many of the systems created have been standalone systems that do not share data. In the late 1960's the Logistics Composite Model (LCOM) was created to allow Air Force leadership to evaluate new weapon systems or modifications impacts on logistic resources and model for logistics manpower requirements [1]. Integrated Maintenance Information Systems (IMIS) was developed in the 1990's to integrate maintenance information such as technical manuals, diagnostic instructions, work orders, supply availability, etc in a single hand-held computer based integrated system [22]. In 1999, AFRL initiated the LOCIS program to research ways of utilizing existing data from current systems such as Core Automated Maintenance System (CAMS) and IMIS, and presenting the information to the Operations Group (OG) Commander, Logistics Group (LG) Commander, and their respective staff. The focus of the LOCIS program was on information fusion, decision support, and dynamic user interfaces [13, 14]. This successful program was a first step in developing integrated information systems to support human decision making.

The vision is to develop SSLC2 to fuse large amounts of location and status information, provide situation assessment, and monitor equipment and human performance in such a way that human operators and technology work together as a symbiotic team. This vision is a warfighter requirement – the right information delivered

at the right time at the right level. Advances in smart sensors, computing technology, information networks, and research in human cognition and performance will help us move in this direction. Real-time sensing technologies can provide myriads of information to help support Air Force logistics. For example, RFID technology is being used to improve In-Transit Visibility (ITV) of equipment and supplies during deployment [21]. RFID tagging is becoming standard within many commercial supply chains. The Autonomic Logistics System (ALS) is a concept to allow automatic detection of aircraft system faults or system deterioration to provide active logistics maintenance information versus the current reactive approach [18]. War fighter physiologic and cognitive monitoring is being utilized to develop smart systems to adapt to the war fighters needs [15, 20].

AFRL is interested in incorporating real time sensing technologies to improve flightline logistics support. This technology, as well as others, has the potential to provide significant impact to flightline decisions. Although off-the-shelf RFID/RTLS technology provides immediate location information on tagged resources, and allows a decision maker to easily find these resources; in its stand alone form it is merely another information stovepipe. So while near real time information is available, it will not necessarily improve flightline decision making. The challenge with sensor technologies is to provide the correct information, at the right time, in the right format to improve human decisions and system performance. Too often, adding the technology without considering the impact creates “shelf-ware.” Often development of new technologies, such as RFID, occurs so rapidly the technology push can lead to flawed technology-centric systems lacking a human centered engineering approach. In the end humans will be the ones using the technologies and systems to perform important tasks, make critical decisions and fulfill mission requirements. Therefore, human performance must be central to system development.

With these considerations in mind the AFRL initiated the SSLC2 Advanced Technology Demonstration Program researching technologies and techniques, facilitated through software, to craft information enabling the warfighter to become more agile, productive and smart about critical logistic resources required for combat operations. It has been recognized that decision support tools must be created to fully exploit real time

information. The SSLC2 program focuses on human performance in complex, time constrained, high-stress, decision making situations and on leveraging technology to assist the human decision-maker by capturing and displaying data in innovative ways to promote more effective decision making on the flightline. The overall goal is to provide decision support on the flightline to improve sortie production resource allocation, personnel and resource scheduling, and decision making at multiple levels.

2.1 THE PROBLEM

Logistics and sortie production mission success depend on resources (people, equipment, and information). Yet few bases manage the availability and performance of their resources from a mission perspective. Resource management is often driven by priorities that are disconnected from the primary mission objectives and end-user requirements. Aerospace Ground Equipment (AGE), test equipment and people are employed in stovepipe fashion, leading to fragmentation and “silos” of infrastructure. This situation leaves managers with no visibility into overall service levels, no way to proactively detect and prevent availability and performance problems, and no means of quantifying the impact of downtime on the pilots, maintainers and the overall mission. It adds up to delays, complexity, over allocation and end-user frustration.

The problem is while there are intelligent, qualified people, equipment information including what resource is needed, the resource’s related location, or its status is not always known. Equipment is used and returned to the ready line or the tool crib without any indication of a change in status. Sometimes equipment is used and then left in place for future known or unknown actions. The AGE driver is left to wonder if this equipment is still needed, ready for return to the ready line, or in need of servicing or repair. People of the same Air Force Specialty Code (AFSC) develop additional qualifications or higher levels of competency in various tasks, but that information is either documented in a manual record, somewhere in a wide variety of databases or, in the case of levels of competency, not documented at all. Many times decisions are made to optimize resource utilization, not sortie production.

To meet the demand for agile combat support a variety of information technology tools are being developed and purchased by the U.S. Air Force. Many of these off-the-

shelf technologies are given to users and they are told to figure out how to use them. In many cases maintenance personnel are developing their own in-house programs to deal with the information they use. With the large amounts of information and complex decisions that occur in the air base environment, it becomes crucial to involve users in the development of technologies, especially decision support tools, built for their use.

RFID and RTLS are examples of off-the-shelf technologies with potential to improve the maintenance process. RFID is sometimes called Dedicated Short Range Communication (DSRC). An RFID system, at a minimum, consists of three components: an antenna and transceiver (often combined into one component called a reader) and the tag, of which there are two types (passive and active). In a simple RFID system a passive tag is used along with a reader which is usually a permanent gateway into a facility. This will only allow for entry and departure readings from a defined facility or area. RTLS uses RFID technology to transmit the physical location of RFID tagged objects. RTLS systems require active RFID tags to be attached to each object needing tracked and Radio Frequency (RF) transmitters/receivers located throughout the facility determine the location and send information to a computerized tracking system. RFID/RTLS technologies with active tagging have the potential to improve awareness related to resource location by showing where things are. If the required piece of equipment is sitting on the flightline, it is not possible to tell, within the current applications, what it is doing out there. It might be in use, out of fuel, awaiting a high priority task to begin, or ready for re-assignment. These capabilities can be accomplished through customization of the off the shelf RFID/RTLS products.

These challenges reflect up to the Major Command (MAJCOM) and/or Air and Space Operations Center (AOC) in the broader context of “will that base meet its sortie schedule and support the mission?” and, “if not, what is the impact?” The characteristics of the current environment include little cross-echelon situational awareness due to a largely manual data capture and decision analysis processes. There remains very little insight to wing-level sortie production capability. Decision making is still limited by the ability to assimilate data into reasoned, actionable information. In the end, off-the-shelf Automatic Information Technologies (AIT) only solves a small part of the situational awareness and decision making challenge.

Flightline maintenance for sortie production can be considered a very complex logistics system. The ultimate goal is to improve Air Force systems to create a more agile Air Force. Complex systems require the management of resources to meet multiple objectives and require substantial coordination among entities within and outside their own subsystems. Enhanced sensor technologies have the potential to provide additional information to support decisions related to the management of logistics support. Flightline maintenance requires:

- the need to monitor, plan and schedule;
- the need for collaboration;
- the need to make real time decisions and changes to current plans and schedules;
- the need to coordinate among many groups or other subsystems;
- the need to predict how changes may affect subsystems and schedules;
- the need to coordinate use of resources to meet multiple objectives;
- managing large amounts of information needed during the decision process and
- the sharing of similar types of data.

These requirements are not unique to flightline maintenance, but are issues with most existing complex systems such as logistics for air and space, health care, disaster management, homeland security, to name a few. Therefore, research on this project will be of benefit to other complex systems.

2.2 SSLC2 PROGRAM VISION

The vision of SSLC2 is to provide personnel decision quality information from multiple data streams including real time location and status data for monitoring capabilities, as well as algorithms to equate resource availability to operational capability. Decision-makers will be provided insight to the operational impact of their decisions. The SSLC2 effort is researching the fusion of technology with information to provide decision support and situational awareness aimed at demonstrating the capability for improved decision making that can affect sortie generation. Functional systems that support maintenance data collection along with developing systems that will contain electronic Technical Orders (TOs), Enhanced Maintenance Operations Center (EMOC) support systems, or even direct maintenance support systems would contain SSLC2

capabilities. In this way, predictive logic can be applied to determine the appropriate resources to use and maintain the highest possible Mission Capable (MC) rates. The SSLC2 vision incorporates Interface Requirements Agreements (IRA) with any system that collects data that would be useful in the management of people, equipment, and information. For example, if medical appointments are contained in a medical system, an IRA can be drafted allowing the extraction of data without violating the privacy of the medical system.

Another vision is that a system would contain job guides, the TO equivalent of a “How To” guide for major maintenance tasks on each weapon system. These job guides detail which major pieces of equipment are required and what follow-on maintenance is necessary. In this way, maintenance management functions can determine logical priority for task accomplishment with a maximized MC rate for the end product.

SSLC2 should continuously monitor all assets in its domain and report a variety of status indicators. Some of those indicators may be current operational condition (is it running), fuel load remaining, built in test status or perhaps data entered by the last user. This means maintenance managers will not only know what is needed for the job but they will, in one look, know where it is and if it is serviced, repaired and available; in short “it is the right resource for the job.” If the resource is fully operational and ready for reuse, the technician has only to put it back where it belongs or have the AGE driver pick it up. SSLC2 has already assessed and published its status.

Information about personnel resources, such as standard AFSC-related details, would be fused from the appropriate system and all AF Form 623 and Job Qualification Standard (JQS) data should be available. In addition, maintenance managers can make personal notes about workers to aid in selecting the correct person.

While the vision is to provide recommendations, the actual decisions and selections would be firmly in the hands of the maintenance manager. The goal of SSLC2 is to provide recommendations that optimize sortie production even if it appears that resources are sub-optimized.

Under the SSLC2 concept, not only will maintainers know where things are, they are provided recommendations as to which resource is most appropriate for the task at hand.

No longer will the operationally oriented decisions be the sole domain of a few highly experienced airmen. While SSLC2 will not make the decisions for the maintainer, it will present all the information needed to make well informed decisions and recommendations.

Enhanced situational awareness provided by the SSLC2 concept can extend across command echelons and provide MAJCOM and Air Force Forces (AFFOR) decision-makers visibility into wing-level operational capabilities. They can look down into the operating locations and determine independently if the resources are in place to meet the flying schedule and Air Tasking Order (ATO). These decision makers can also quickly assess the impact of any degradation of sortie capacity.

SSLC2 is the logical conclusion to meet future needs of the Air Force. The SSLC2 research program is a key project toward facilitating informed decisions at multiple levels.

2.3 SSLC2 SPIRALS

The SSLC2 program had three Spirals. Spiral One was scoped on wing-level personnel concentrating on one primary decision, the fix/swap decision of an aircraft. During Spiral One, researchers investigated and validated the cognitive model of Expeditors on the flightline and compared commercial off-the-shelf (COTS) RFID technology (WhereNet) for supporting user tasks with a system in which sensor information was integrated with flightline information (SSLC2). The results indicated that users preferred the SSLC2 integrated approach. (See Spiral One Final Report for more details [10].)

Spiral Two was used to enhance a separate program contract called Virtual Space Logistics Readiness Center (VSLRC) as a modification to the SSLC2 program providing the Air Force Space Command (AFSPC) and Space and Missile Systems Center (SMC) an actual implementation of the SSLC2 concepts. Rather than using RFID/RTLS technology, VSLRC fuses data from numerous AFSPC sources to provide logistics status of space ground assets to determine their operational capability. (See Spiral Two Final Report [11].)

Spiral Three continued the work from Spiral One but expanded the research to investigate the smart sensors and the fusion of information for multiple tasks and problems that occur on the flightline and also investigated how to support the collaborative nature of the tasks and sharing of logistic resources. Spiral One and Spiral Three were directly linked with information gathered during Spiral One related to the cognitive work models and user feedback used as input to Spiral Three. Originally, an in-depth scientific study with users across several airbases was planned with the intention of collecting objective human performance data as well as user opinions to meet Key Performance Parameters. Unfortunately, during the Spiral Three phase, the entire project had to be re-scoped due to time and cost constraints.

2.4 PROGRAM SCOPE

SSCL2 is a 6.3 Advanced Technology Demonstration (ATD) program researching ways to make the human warfighter more agile, productive and smart about the critical logistic resources required to support combat operations. SSLC2 is an effort to make existing systems “smarter” by utilizing data collection sensor technologies and fusing data with existing information systems to improve Logistics Command and Control decision making. The program produces research, science and methods, and evaluates how existing technologies can be value-added enhancements to existing/forthcoming systems. The SSLC2 goal is to research, demonstrate, and position for transition, technology capabilities that can be applied to and integrated into existing systems to produce logistics-based operational capability awareness. Spiral Three demonstrated technologies and this report specifies requirements that enable near real time monitoring of information on critical aspects of the logistics infrastructure. SSLC2 is not generating a new information system, but generating requirements and specifications that can be transitioned to an existing legacy system. Techniques and tools that can best enable logistics decision-makers to have a high-level view of logistics operations, identify potential problems, and make proactive decisions at various nodes within a logistics support environment are identified and validated.

2.5 DOCUMENT OVERVIEW

The Spiral Three Final Report presents the main activities associated with the SSLC2 program during Spiral Three. Section 3 presents the Research Approach which provides details of the objectives and the six step process used to reach the objectives. This section presents the design concepts, the final interface designs, as well as hardware and software architectures. Section 4, Scientific Study Approach, presents the details of the study methodology for the field demonstration. Section 5, Results and Discussion presents the user feedback results obtained during the field demonstration. Section 6 presents Recommendations and Section 7 is Conclusions and Appendix A defines Acronyms used in this report.

3 Spiral Three Approach

The goal of SSLC2 Spiral Three was to investigate ways to support logistic decision makers in complex flightline operations through the fusion of existing flightline information with smart sensor information. The focus was on providing support to Expeditors and ProSupers on the flightline. The five research objectives were as follows:

- Objective 1: Develop smart sensors for logistics operations.
- Objective 2: Develop a method for determining how data should be fused for presentation that focuses on supporting decisions and collaboration.
- Objective 3: Obtain user opinions of deployed sensors in the field.
- Objective 4: Develop a simulation test bed and evaluate user feedback on integrated data fusion decision support concepts.
- Objective 5: Develop recommendations for transition to existing systems.

In order to meet these objectives a research approach was defined with six primary steps as listed below and illustrated in Figure 1.

1. Determine the information and decision requirements that are needed to provide decision makers a shared vision and support collaboration. Work with RFID suppliers to develop smart sensors.
2. Develop a conceptual design for an interactive visualization to present sensed data fused with flightline data.
3. Present conceptual design ideas to SMEs and refine concepts.
4. Develop a simulation test bed to provide the ability to demonstrate concepts and receive feedback from system users.

5. Present concepts during a field demonstration using the test bed and receive feedback from systems users.
6. Develop recommendations and requirements (updated from recommendations and requirements from Spiral One).

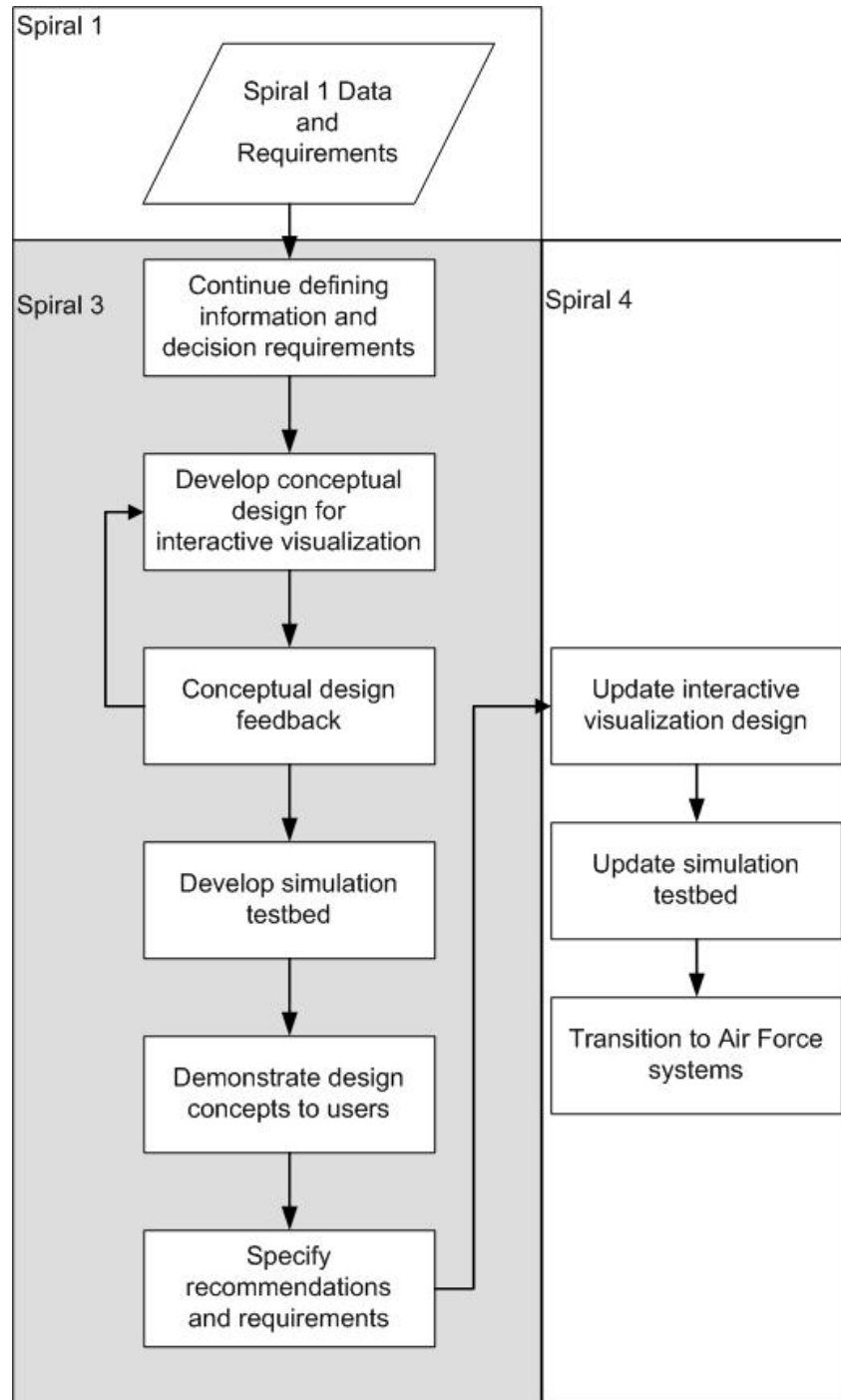


Figure 1. Research Steps

As illustrated in the figure, information from Spiral One related to Expeditor and ProSuper tasks [10] and decisions as well as requirements were used as input to Spiral Three. As mentioned in Section 2.3 of this report, Spiral Two [11] concentrated on visualization for air and space and was not directly tied to SSLC2. This section of the report (Section 3.0) briefly summarizes Spiral One inputs and describes steps 1- 4 of Spiral Three. Steps 5 and 6 are described in sections 4.0 and 5.0 respectively. Output from Spiral Three provides direct input to Spiral Four.

3.1 INFORMATION AND DECISION REQUIREMENTS

Fusing information from sensors with flightline data to provide shared understanding among personnel, to improve decision making, and to impact logistic operations requires presenting the information in such a way that the user can understand the information and act on it. Development of intuitive interactive visualizations requires a systematic approach that includes a focus on the user, understanding what information is required to make decisions and to enhance effectiveness. The visualizations must integrate information, providing the right information at the right time. While there are general guidelines when developing visualizations, there are no specific rules that are guaranteed to provide useful intuitive visualizations. The most successful visualizations require a user-centered approach which includes a requirements gathering stage to develop a thorough understanding of the information users need, how they perform their work and the decisions they make. There are several frameworks described in the literature that focus on a user-centered approach. Mayhew [16] describes the user-centered lifecycle approach for the development of software systems. There is the Work Centered Support Systems (WCSS) concept described by Eggleston and colleagues [3,4]. This concept focuses on the development of systems that support user work. Another method is the Applied Cognitive Work Analysis (ACWA) described by Paradis, et al. [17] and Gualtieri, et al. [12].

All of these frameworks are similar in that they are focused on performing up front cognitive work analysis to understand what the user needs and transforming the data gathered into actual design of user-interfaces or visualizations. The ACWA framework

describes the need for mapping the data and information into a visualization for the purpose of decision support. Even with these concepts, the difficulty lies in moving from information to design. No framework provides guidelines for the specific design of visualizations because visualizations are primarily domain and/or work dependent. Visualization design is both an art and a science, requiring creative ideas combined with knowledge of human capabilities and limitations related to both human cognition and visual perception.

In addition to gathering information and applying it to design, the user-centered process also includes evaluation of the concepts. Design concepts are evaluated early and iteratively during the process. It is also important to apply knowledge of human perception and cognition, guidelines for the development of visualizations, and human-computer interaction guidelines. For example, visualizations should be designed to minimize the need for users to rely on their memory. The ability to provide the user with situation awareness is an important aspect of the system. For this application the system will be used outdoors and therefore display contrast and luminance output capabilities and color choices are an issue. The use of color in most outdoor applications is limited because of the loss in contrast, and based on military standards we must have redundant coding if color is used.

3.2 SPIRAL ONE SUMMARY

Spiral One's objective was to compare the use of commercial off-the-shelf (COTS) RFID technology (WhereNet) for supporting user tasks with a system in which sensor information was integrated with flightline information (SSLC2). This phase helped to gather additional system requirements for future phases. To develop the SSLC2 interface for this evaluation, a user-centered approach was followed. The first step consisted of systems analysis and cognitive work analysis (CWA) with data collected from subject matter experts (SMEs) at various Air Force bases through job shadowing and interviews. The second step focused on concept development and storyboard designs with SMEs participating as part of the design team. The third step developed use cases from the storyboards to create a simulation of the interface to allow for user testing. The focus of

Spiral One was to support one decision; the fix/swap decision. The flightline information included was for only one maintenance day.

The SSLC2 general interface concept is illustrated in Figure 2 which presents the geographic view. The interface provided the user with aircraft status and location, daily flying schedules, personnel and equipment resources and their locations, tasks necessary to fix or swap aircraft, time to complete, time to move resources to the fix site, and types necessary to complete tasks, specific resources assigned to tasks, and a recommendation to fix or swap an aircraft. Users could also view the information using a flying schedule view. The left side of the screen presented the workflow process steps. The central portion of the screen provided the schedule and geographic views. The views could be changed from an overview of the entire flightline, to a problem view focusing on one aircraft. Users could interact with the system using a mouse and standard keyboard.

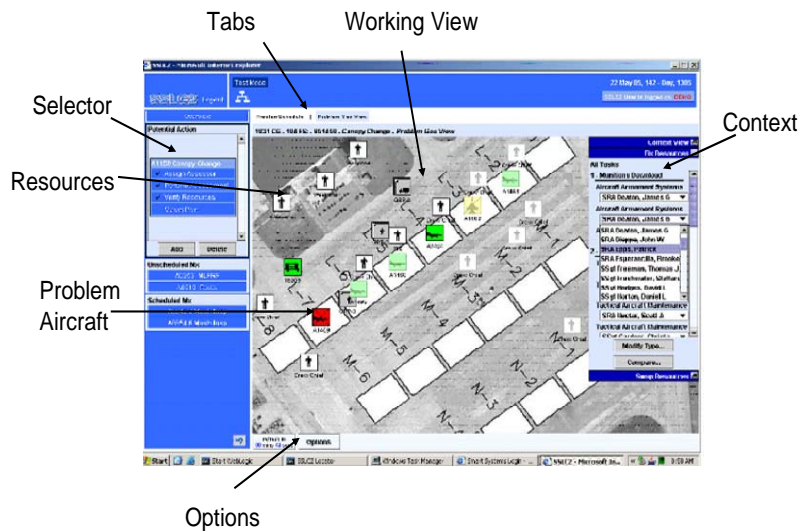


Figure 2. Spiral One Conceptual Design

3.2.1 User Feedback Spiral One

Fifteen maintenance personnel from four airbases interacted with the interface in a simulation. All participants had ProSuper and/or Expedito experience. A great deal of data was collected on user feedback for this design and in-depth details can be found in the Spiral One Final Report [10] and in Gallimore et al. [8]. In this section we describe some of the issues noted by users related to the interface. Participants made positive comments about the ability to see a flightline overview, both geographically and as a

schedule. ProSupers and Expeditors are expected to multi-task and respond to more than one problem at a time. Participants suggested that a future system provide them the ability to multi-task and display information about every aircraft in order to support decision making.

SSLC2 also broke down each problem into a series of tasks to be completed (a work centered approach). Each task listed associated equipment and personnel resources with their time to site and time to fix. Participants voiced their support for seeing the list of tasks and said they would use this feature. Participants also said they would prefer the ability to create or modify the tasks needed to fix problems. Participants indicated that having the entire listing of tasks and resources was overwhelming. Participants sometimes referred to the wrong task when trying to change a resource, and indicated too many steps were required to reallocate resources (up to eight). Participants wanted a click and point interface rather than dialog boxes and pull downs. Additional items and comments highlighting positive aspects of SSLC2 functionality included the ability to zoom in and out within the geographical views. The results indicated that users preferred the integrated SSLC2 approach to the off-the-Shelf WhereNet system that only provided resource location information and no flightline information [8,10].

3.3 DECISION AND INFORMATION REQUIREMENTS MAPPING

ProSupers and Expeditors make many decisions requiring significant collaboration among personnel and organizations. Multiple users need access to shared information and it must be provided beyond one day. Spiral One was not meant to tackle all these issues, and feedback from Spiral One was important for Spiral Three. However, it was determined that to incorporate multiple aircraft maintenance problems and to include all the data related to the flightline beyond one day, the Spiral One interface would not be adequate. There were too many menus and steps to get to important information. The interface developed in Spiral One had both positive and negative aspects.

The user-centered approach for Spiral Three was similar to that used in Spiral One, however, additional information related to decisions made and information needed for Expeditors and ProSupers was gathered in Spiral Three by reviewing a variety of flightline documents from multiple U.S. bases, training manuals, and working with

SMEs. SMEs included personnel from AFRL Logistics Research Branch as well as discussion with personnel at Seymour Johnson Air Force Base which was considered as a possible test site. From this data specific decisions were gathered. The decisions were presented to SMEs who then narrowed down the decisions to thirty-one which are presented in Table 1.

Table 1. Decisions Made by ProSupers and Expeditors

	Decision
1	How can I schedule the maintenance to maximize A/C availability?
2	How can I schedule the maintenance to take advantage of heavy maintenance?
3	How will unscheduled maintenance affect phase flow?
4	How should I schedule CANN rebuilds? Affects manpower.
5	Are sufficient personnel resources and types available today (now)?
6	Are sufficient equipment resources and types available today (now)?
7	Are required parts available for maintenance actions? What is the status of backorders?
8	What facilities are needed and available for current maintenance operations?
9	Can scheduled aircraft meet the sortie?
10	Can NMC aircraft be repaired in time to meet schedule (in a line or as a spare)?
11	How does the CANN/Hangar queen rebuild affect unscheduled maintenance?
12	Are sufficient and properly configured spares available? Are they configured for takeoff?
13	Which aircraft problem has priority?
14	Must aircraft configuration be changed?
15	What maintenance actions are needed?
16	What is the priority of repair? E.g. Might be PMC and can make next flight so priority is lower than another PMC or NMC
17	What servicing is required?
18	What is the initial assessment of the problem?
19	Should Cannibalization be used to solve the problem?
20	Should the problem be solved by swapping the A/C?
21	Should the mission be delayed?
22	Should the mission be cancelled?
23	How will the problem affect/impact the flying schedule?
24	What are the causes for maintenance deviations (cancellations, aborts, additions or early/late takeoffs)
25	What are the estimated fix times? (How long will it take to fix, configure, CANN, etc)
26	Are specific aircraft, equipment, systems, or subsystems contributing to a disproportionate share of deviations/turbulence?

	Decision
27	Are there seasonal or cyclical variations? Are current variations outliers?
28	What factors are causing an increase or decrease in the NMC rates?
29	How do today's problems affect my schedule tomorrow given different maintenance issues that are on tomorrows schedule, next week, etc.
30	How does a change in personnel availability changes affect my schedules?
31	Which task that I personally need to complete has priority? (e.g. monitor a take off vs request something)

In addition to establishing the decisions, information or data elements that are used on the flightline were compiled. A list of 157 different data elements was created. (See Appendix B, Data Elements, for full list).

For visualization design it is important to understand how the data elements map to the decisions. Not all information is needed for each type of decision. The goal was to provide users with easy access to data based on decisions they make. Current frameworks discuss the need for the CWA and understanding of the information and decisions to be applied to design, but moving from this information to design can still be difficult. The results of the CWA during Spiral One were an important input.

3.3.1 Cluster Analysis

In order to perform a mapping of what information is needed for different decisions and to determine the importance of information we decided to use a cluster analysis technique. A data matrix was created with the 31 decisions in columns and the 157 data elements in rows. Three SMEs were then asked to read each decision and rate the importance of the 157 data elements to that decision. They rated the information on a scale of 1 to 5; 1- not at all important, 2 - somewhat important, 3 - important, 4 - very important, and 5 - critical or extremely important. In addition to the 31 decisions they also provided a rating to indicate whether the data element should be visible most of the time.

The ratings were used as input for the cluster analysis. A hierarchical cluster analysis using Ward's method was conducted within the JMP Professional statistics package (Version 5.0.1.2). The ratings were first averaged across the three SMEs. The cluster analysis was conducted across all decisions to be made. The analysis resulted in 28 clusters of the 157 data items. Appendix B, Data Elements, provides a summary of the

cluster results in a table. The table includes a column which provides the average rating of subjects' responses across all 31 decisions.

The data items were also examined by the average rating for the question of "important data to be visible most of the time". The second column of the Table in Appendix B, Data Elements, provides this rating.

Eighty-nine of the 157 data items were given an average rating across all decisions of less than 2 indicating they were considered "not at all important" by the SMEs. Table 2 is a reduced table for data elements that received average ratings of 2.0 (somewhat important) or above across all decisions. The data elements in this table are ordered from highest rating to lowest rating.

Table 2. Data Elements rating 2.0 or higher

Data Element	Rating
Current Discrepancies	4.48
Nature of problem.	4.48
Tail number (element aircraft)	4.38
Reason for status	4.23
Tasks required to solve problem	4.23
Schedule for day (Current time and date, all aircraft, Status, brief time, take off time, land time duration of flight, load, remarks, turn, weather, Phase?)	4.19
ETIC	4.15
Status (PMC, NMC, FMC, spare, CANN)	4.06
Priority of task	3.95
Discrepancies awaiting parts	3.58
Scheduled Maintenance	3.57
Safety/Danger Considerations (power/hydraulic applications, stress panels removed, aircraft on jacks, weight and balance, etc.)	3.56
MICAPS	3.53
Corrective actions (maintenance)	3.49
Personnel current a/c working or task	3.47
Discrepancies awaiting maintenance	3.38
Personnel Availability	3.34
Priority of sorties	3.32
take-off time	3.31
Schedule changes	3.27
Lines required for filling	3.10

Data Element	Rating
Service item status, requirement for next flight	3.10
Status of backorder parts	3.03
Supplies in stock, Inventory levels	3.03
Schedule for the week	2.91
Availability of critical equipment	2.90
Current Configuration	2.89
Location on flight line	2.84
Qualification Levels (3-level, 5-level, 7-level)	2.81
TCTO (Time Compliance Technical Orders) - Safety Issues - Contains A/C Tail Number, Date	2.77
OTI (One Time Inspection) Tail Number, Date	2.76
Personnel qualifications, certifications	2.74
Mission Requirements	2.73
Land time	2.71
A/C Projected to be Spares	2.71
A/C Projected to be Prime Flyers	2.71
Weather forecast	2.70
TCI (Time Change Item)	2.69
MESL (for mission, basic and full)	2.65
Personnel role (crew chief, specialist, etc)	2.63
List of CANNED items	2.61
Turn	2.55
Line number (details type of sortie)	2.55
Type of a/c (Model)	2.49
Type of sortie on schedules (night, XC, training)	2.48
A/C Projected to be USM	2.47
Crew chief currently assigned	2.47
Top Supply Drivers/Parts that have problems	2.42
Work Unit Code	2.42
Shifts Scheduled	2.39
Stage of CANN jet	2.38
Past week maintenance history	2.33
Load	2.27
AFSC	2.23
Personnel Current location	2.22
Rules for exceptional releases	2.20
Maintenance Training Requirements	2.20

Data Element	Rating
Ground Time Requirements	2.19
a/c load	2.19
Scheduling guidelines	2.18
Days/time since last flown (hangar queen)	2.14
Personnel Contact info (name, radio call, or other)	2.11
Supplies on order and expected delivery date	2.10
Aircraft with pacer motors identified.	2.05
Equip Availability	2.05
Work schedules (shift)	2.03
Equip Current status (broke, not broke)	2.03
Scheduled Maintenance Requirements (Generic high level used to create yearly forecast - example: average 1 A/C out per month for depot)	2.01

The results of the cluster analysis helped designers determine grouping of information and a general design concept.

3.4 CONCEPTUAL DESIGN

Based on output from Spiral One (CWA, concept maps, field test results) and continued analysis during Spiral Three of user tasks, decisions, data, and cluster analysis, a conceptual design was developed. Important design considerations were learned from Spiral One. User's mental model of flightline maintenance is directly tied to the flying schedule and decisions are based on this information; therefore, a flying schedule is crucial. Users also need to understand maintenance occurring on aircraft and the concept of seeing the specific maintenance subtasks was a feature that users liked about Spiral One. Users also liked the concept of a geographic view for visualizing where resources are located, although exact locations were not very important to Expeditors for most equipment. The ability to locate personnel was important to most users as they often spend a great deal of time searching for people. Another recommendation from the Spiral One report was that the SSLC2 interface should be a direct manipulation interface to include features such as point and click and drag and drop to reduce the need to drill down into many submenus to find information. Because of the large amount of information available there is also a need for sorting and filtering information so the user

does not become overwhelmed and can easily find the information they need. Portability was another key feature as Expeditors are usually in their trucks on the flightline.

An interactive visualization concept was created to fuse the data and keep the information in logical presentations related to how Expeditors and ProSupers think of, and perform their work. The concept was to provide a direct tapping interface for use on a Tablet PC and provide users with global awareness of information and more detailed relevant information as needed without requiring users to continuously drill down through many levels. The visualizations should allow users to sort, rearrange, promote, focus, filter and spotlight data. Users must be able to make notes, highlight information, and collaborate with other users. Shneiderman's [19] concept of Overview first, zoom, filter, sort, and details on demand was followed. The conceptual designs were created in Adobe Macromedia Flash in order to present the concepts to SMEs.

The conceptual design is a tab-based interface to allow users to easily point to the needed information. The primary grouping of information on the tabs are: flying schedule, maintenance, personnel, equipment, facilities, fleet health, and additional resources (checklists, AF documents, lookup information). This Spiral concentrated on all views except fleet health and additional resources. Figure 3 illustrates the general concept. The display is divided into four primary areas: A primary (content based) window, a geographic (geo) view, a detailed data view, and a message area. The information from the geo and detail window can switch places with the primary window so that a larger view can be seen. The information in the primary window always drives the information to be displayed in the detail and geo views, even when the windows change location. Because the window panes are limited in size it is necessary to allow the user to visualize the information without requiring them to continuously scroll. Therefore the concept calls for the use of zoomable user interface (ZUI) using space-scale techniques [6].

Note the window layout for conceptual design in Figure 3 is not drawn to scale.

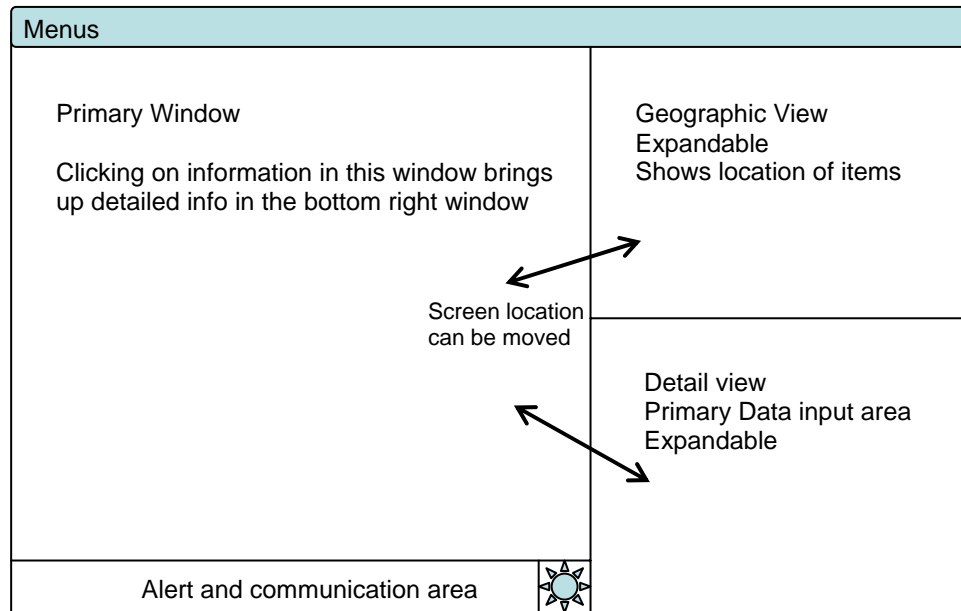


Figure 3. Window Layout for Spiral Three Conceptual Design

3.4.1 Flying Schedule

Figure 4 illustrates the design concept of the flying schedule using Adobe Macromedia Flash. The purpose of this view is to show the current day, week or month of scheduled sorties and all relevant information related to the aircraft and sorties. The frame of reference is a time line with schedules. This is similar to the concept in Spiral One. This view requires the ability to chose the time frame by which to work; hours, day, week, etc, with the user in control of how much of the schedule to view at one time. For example, users may want to view the entire week at once, and then zoom into a specific time frame within that week. All aircraft that are overseen by the Expeditor are visible on the schedule view, even if they are not flying on a specific day. The user is able to filter and sort the order of the aircraft presented to help with decluttering and organization. If the user selects an aircraft icon on the left, specific details related to that aircraft are shown in the details pane, such as status, phase, turn, etc. The aircraft icon also provides information in the way it is color coded and the symbol direction providing redundant coding. If the user highlights the icon by selecting it, the location of the aircraft on the flightline is shown in the geo view.

The information related to the sortie is shown on the time line with important elements such as milestones (inspections, crew ready, crew show, takeoff, landing, etc)

also shown on the timeline. Additional information elements important to users responsible for the management of sortie mission schedules and aircraft preparation are shown below the sortie time line, such as aircraft configuration, load, turn time, hours to next phase, and Estimated Time in Commission (ETIC). Each of these items is selectable in order to bring up more details related to that data element. In current practice, Expeditors and/or ProSupers write down the time when events occur on their paper schedules. This interactive visualization allows the milestone markers to be tapped so that the computer marks the time, with an ability to edit that time if they did not have an opportunity to mark the event in real time.

Additional functionality from this screen includes the ability to swap an aircraft. When a swap is recommended by the Expeditor, sent to and approved by the ProSuper, the 2407 form required for this change is automatically filled in and sent the Maintenance Operations Center (MOC).

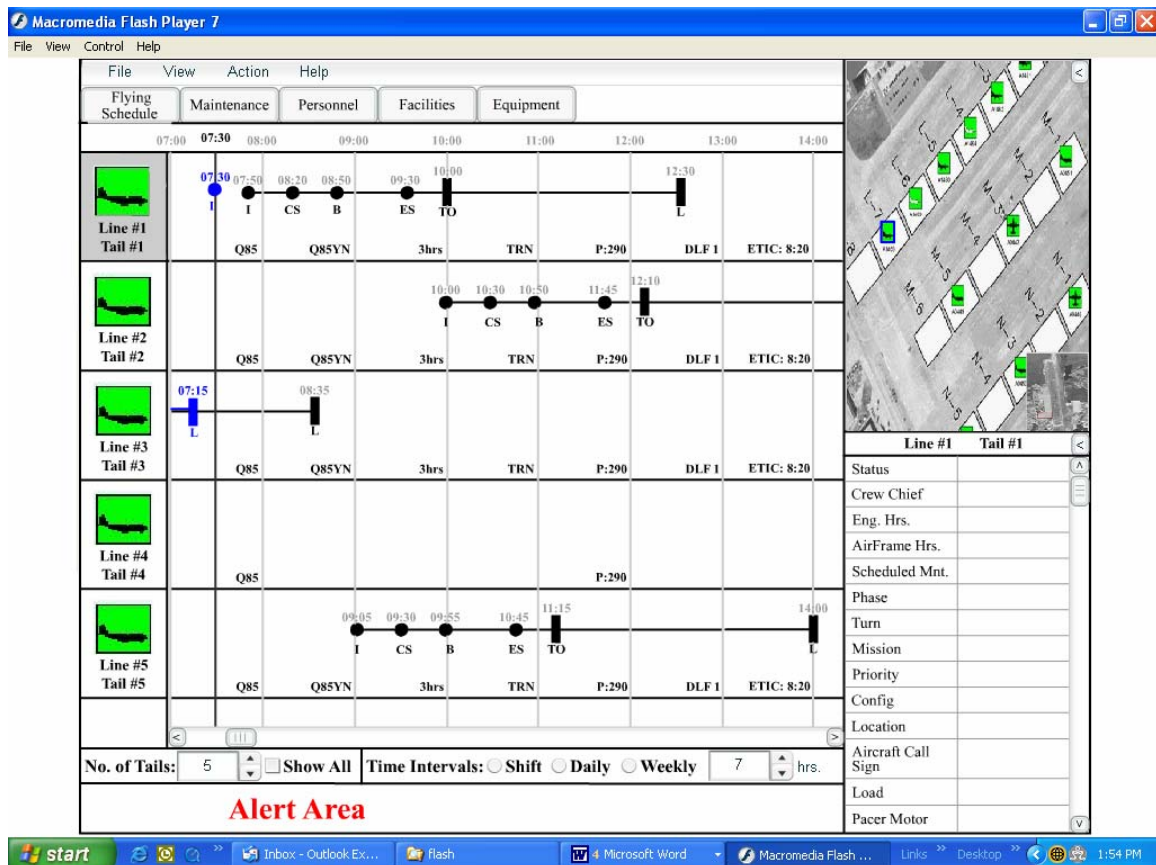


Figure 4. Flying Schedule Concept Design

3.4.2 Maintenance

Monitoring and expediting unscheduled maintenance is a primary job of the Expeditor. In Spiral One the Expeditors were provided with a list of the sub-tasks needed to complete a work problem, the time required for each step and a recommendation for resources. The user could change task times and resources and the system would provide new time estimates based on the time to get the new resource to the location. However, the users indicated that the time changes were so minor that they did not consider it necessary unless there is a major scheduling conflict with resource use. However, conflicts with resource use were not included in Spiral One. Also, the time estimate algorithm was based only on straight line travel which is not feasible for the flightline.

Two concepts for the maintenance view used to display information about maintenance tasks and resources required were originally considered; a list concept and a diagram concept. Each concept is briefly described below. The final choice for the conceptual design was the diagram concept.

3.4.2.1 List Concept

The list concept is to display a detailed listing via textual presentation of all necessary subtasks and required resources needed to fix an aircraft. The advantages of this concept are that user can see a list of tasks and resources needed for each task together and in detail and that the list might be preferred because it is similar to how they read their current maintenance schedule. However, the disadvantages are that it requires a lot of reading, does not provide the user with global situation awareness, and does not allow the user to quickly glance at information to determine if some specific issues have arisen. The list requires substantial scrolling. It is also difficult to compare resource needs across aircraft.

3.4.2.2 Diagram Concept

The purpose of the diagram concept is to provide a global visualization that allows the user to:

- Receive an overall impression and be able to perform quick assessment of the tasks involved to fix aircraft;
- Visualize the flow and timing of tasks, including those that can occur simultaneously;
- Determine if there are any resource conflicts on a task; and

- View multiple aircraft at the same time.

Figure 5 illustrates the concept. The frame of reference is a vertical time scale and the ability to display multiple aircraft horizontally. The subtasks required to complete a maintenance task are presented as a flow diagram, flowing vertically from top to bottom in line with the tasks start time. The time line is shown on the left side of the display. The user can select the time frame by which to view the information using zooming functions. Current time is marked on the time line. Each subtask is specified by a box that is broken into rows that provide quick details related to the tasks including resources assigned. For example, the text indicating type of personnel needed is included. The user may zoom in on subtasks to see more detailed information. When the user puts his/her cursor over the subtask box, it expands in size so that all relevant information can be read. The other boxes are reduced in size but still be visible to show the layout of the task sequence (e.g. zooming techniques such as Fisheye). If the user selects a row on a box, the pertinent information is displayed in the details view. Completed tasks are highlighted (or grayed out). Areas of concern are highlighted (color coded) within each box when there is a potential conflict or if the task is running late. With this concept, users can glance at the tasks and quickly determine if there is an issue, such as a conflict or overdue task, and concentrate their efforts on problem solving.

Currently, Expeditors make notes related to maintenance, so the maintenance view also provides the ability to write and read notes. This view allows the user to make changes to the tasks in terms of start and end times and resources assigned. Some possible data entry methods to consider include drag and drop techniques to allow the user to change start and end times, clicking on the individual rows to allow users to change resources and make notes, or clicking on a subtask to open a window where all subtask data can be entered simultaneously.

The advantages of this technique are:

- Provides an overall impression and quick assessment of the tasks involved to fix aircraft.
- Provides an indication of the most efficient task flow (including tasks that can be done simultaneously).

- Provides quick visibility of any conflicts that must be considered related to resources.
- Ability to view multiple aircraft at the same time for comparison.
- Provides support for ability to balance multiple tasks and resources against multiple problems.
- Provides situation awareness of multiple aircraft but allows user to reach more detailed information on demand.
- Relies on the use state of the art visualization techniques, such as ZUI and fisheye lens, to keep the user aware of where they are in the problem.

The Disadvantages of this technique are:

- Requires drill down into information.
- Designers must be careful in design of coding schemes.

Based on the advantages of the diagram concept, it was selected as the conceptual design to be presented to SMEs. Figure 5 depicts an example of this design concept for the maintenance subtask view showing tasks and subtasks, drawn using Adobe Macromedia Flash.

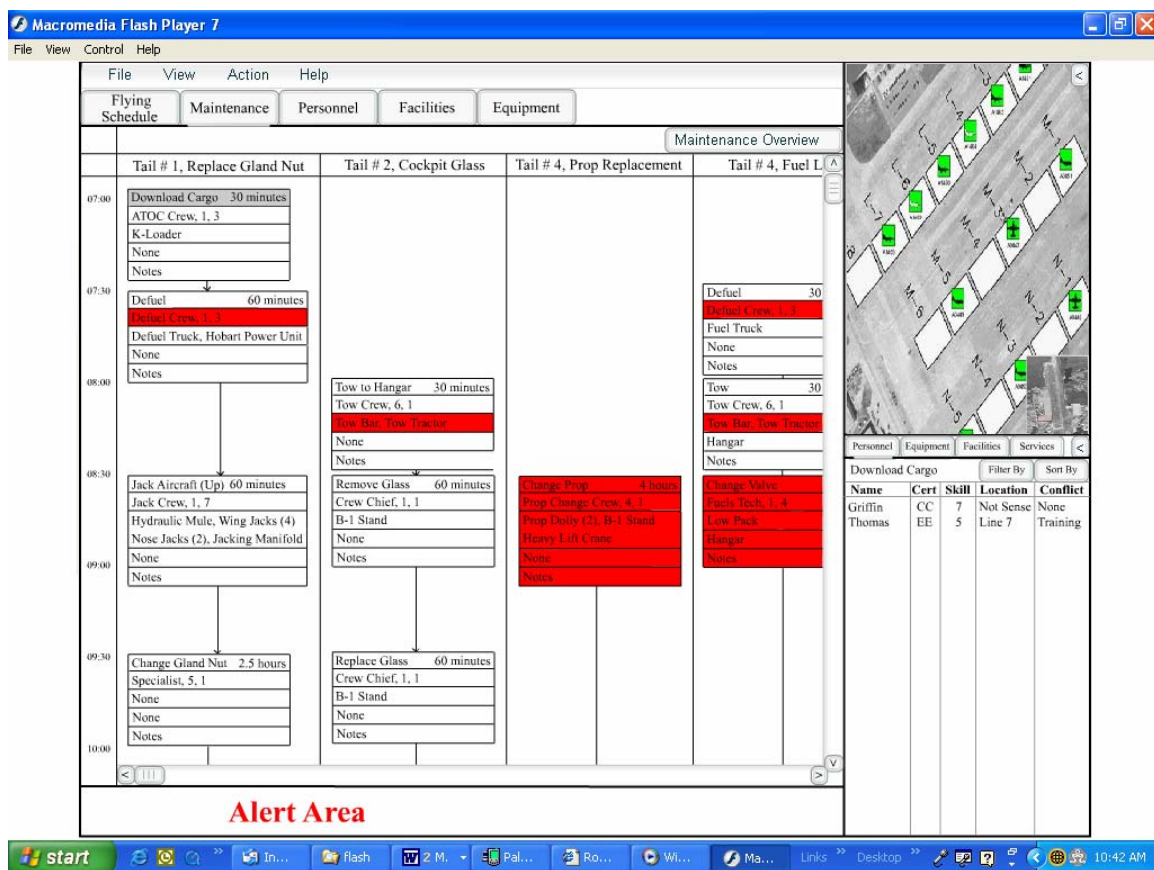


Figure 5. Subtask Maintenance Concept Design showing tasks and subtasks

To enable the user to determine which aircraft's maintenance tasks to view in the subtask maintenance screen, an overview of all maintenance tasks is needed. The maintenance overview screen (see Figure 6 drawn using Adobe Macromedia Flash) is a list of tasks for each aircraft. The user may select the specific tasks they want to view on the subtask screen by checking the boxes next to the tasks and expanding the selected items at which point the flow diagram of the subtasks are shown. This screen also shows coding related to any problems that may be occurring in a maintenance task including conflicts and overdue tasks. In this way the user can concentrate their efforts on those tasks which show issues and obtain more specific details, yet see a list of all tasks currently required on an aircraft (scheduled and unscheduled).

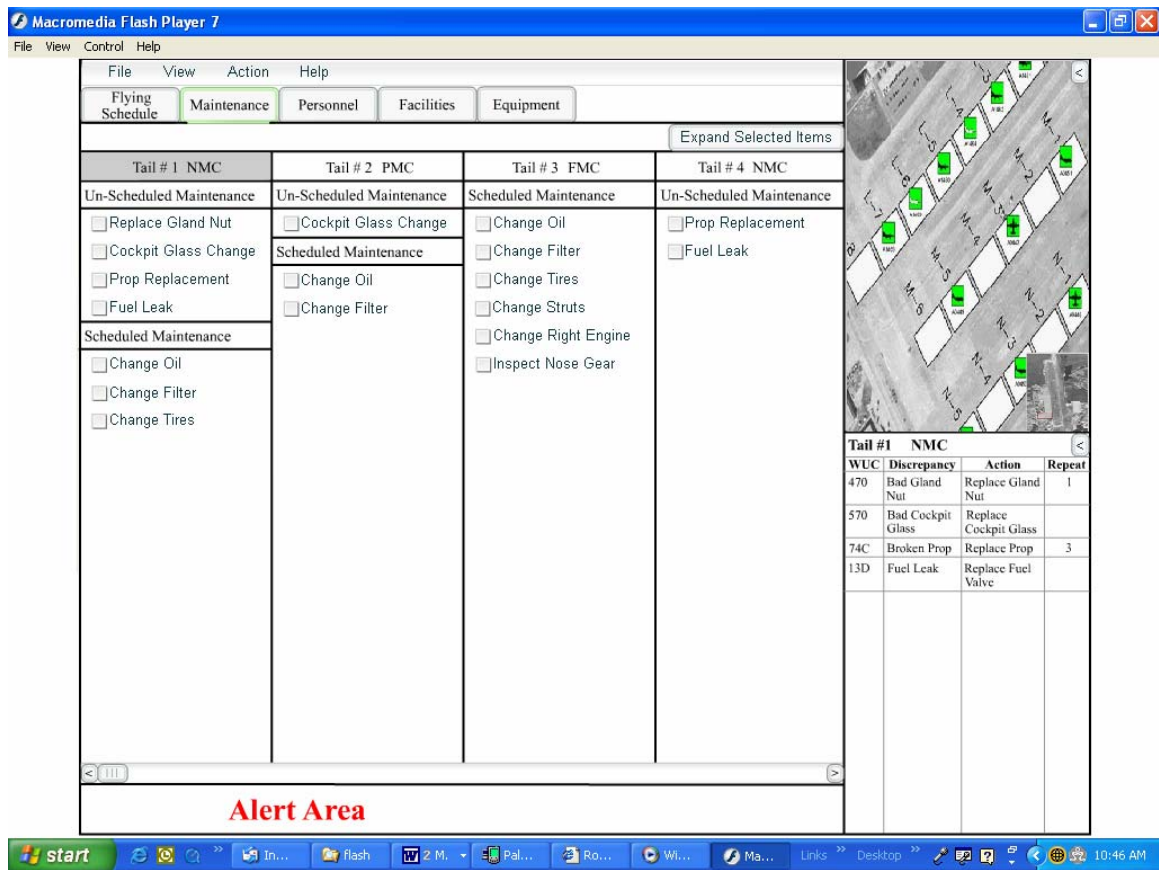


Figure 6. Overview of maintenance tasks concept

3.4.3 Equipment

Expeditors primarily rely on others (e.g. AGE yard) to find and bring equipment to the aircraft being maintained. In some cases when they have an immediate need they search for equipment on the flightline, pick it up with their truck and bring it to the work site. They may then realize it is not functioning. It is not unusual for Expeditors or others

to be looking for a specific resource. The purpose of the equipment view, shown in Figure 7 drawn using Adobe Macromedia Flash, is to provide the user with a global awareness of resource availability as well as more detailed information if needed. The frame of reference is the specific equipment resources and their current status as well as future status information related to assignments to future tasks. For example if a piece of equipment is assigned to a task at a specific time, this information is shown in the details view. The concept is to allow users to quickly glance at equipment to determine status (e.g. broken, in conflict, available). If they notice that many of their low density high demand resources are broken, that knowledge allows them to consider how resource availability may affect their maintenance so they can plan accordingly. It also allows them to easily locate a piece of equipment on the flightline. Equipment is displayed on the primary view using icons and redundant color and shape coding to designate their status. If they need specific details, such as location or tasks to which the equipment are assigned, they can tap on the equipment and see the details in the detail pane and the equipment is shown in it's current location based on RFID tags on the flightline. Users are able to sort, filter and zoom on this view, an important requirement given the large number of possible equipment resources.



Figure 7. Equipment view concept design

3.4.4 Personnel

Personnel are also resources. In Spiral One, Expeditors indicated that finding people was a very time consuming task. The concept for the personnel view is similar to the equipment view; however, the frame of reference is a schedule with a time line. Active personnel tags on badges could provide location as well as availability. The personnel view displays the person's name on the left and their schedule on the right. Like the flying schedule, this view requires the ability to chose the time frame by which to view the information (hours, day, week, etc.) with the user in control of how much of the schedule to view at one time. The user can filter and sort in order to declutter and organize the data and only show information of interest, or by work group (e.g. view all crew chiefs). Users can also search by name. Selecting the personnel icon on the left places detailed information related to that person in the details pane and shows the location of the individual on the geo view. The schedule indicates what tasks personnel are assigned and also conveys if they have been assigned to multiple tasks at the same

time causing a conflict. Figure 8 depicts the conceptual design for the Personnel view, drawn using Adobe Macromedia Flash.

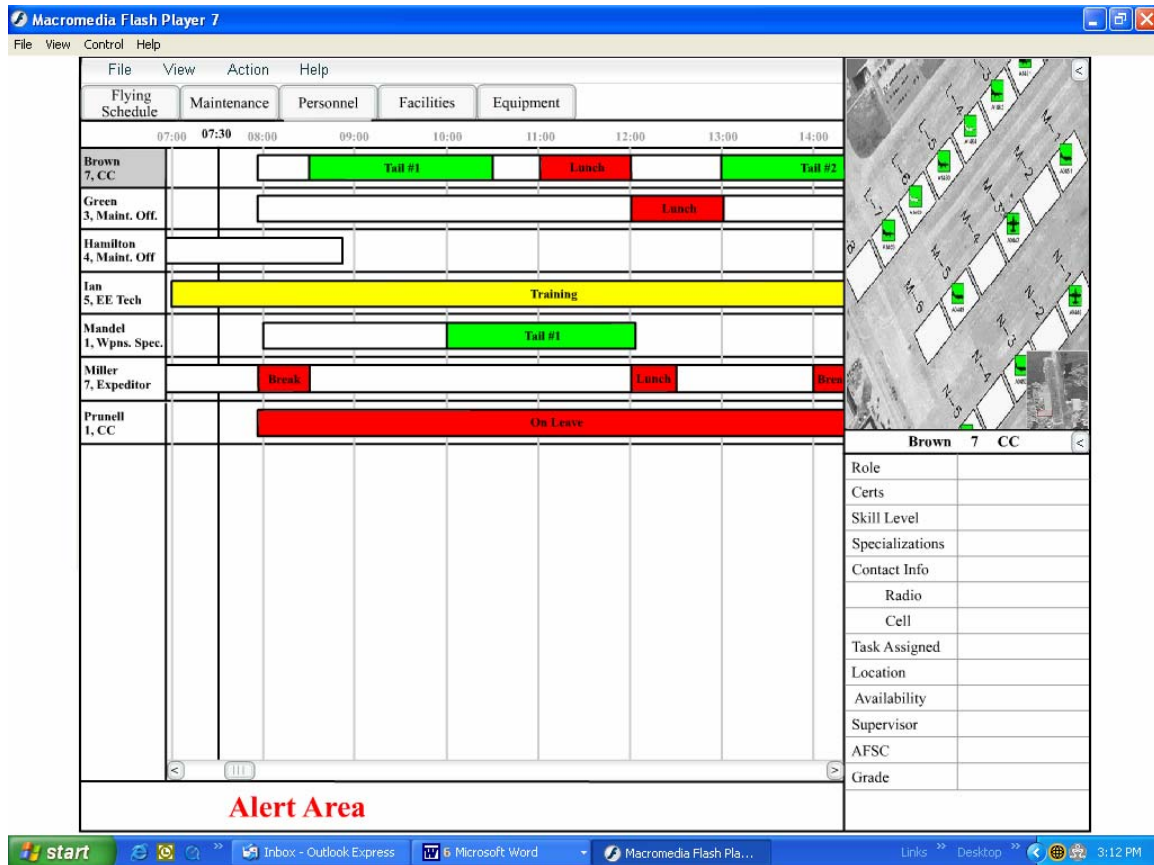


Figure 8. Personnel view concept design

3.4.5 Facilities

Figure 9 illustrates the design concept for facilities, drawn using Adobe Macromedia Flash. Maintenance may occur on the flightline at various facilities. The frame of reference for this view is a schedule view which shows the aircraft assigned to the facility and the time. Details related to the facility or schedules are available in the details screen. Users may also schedule their aircraft to a facility from this view.

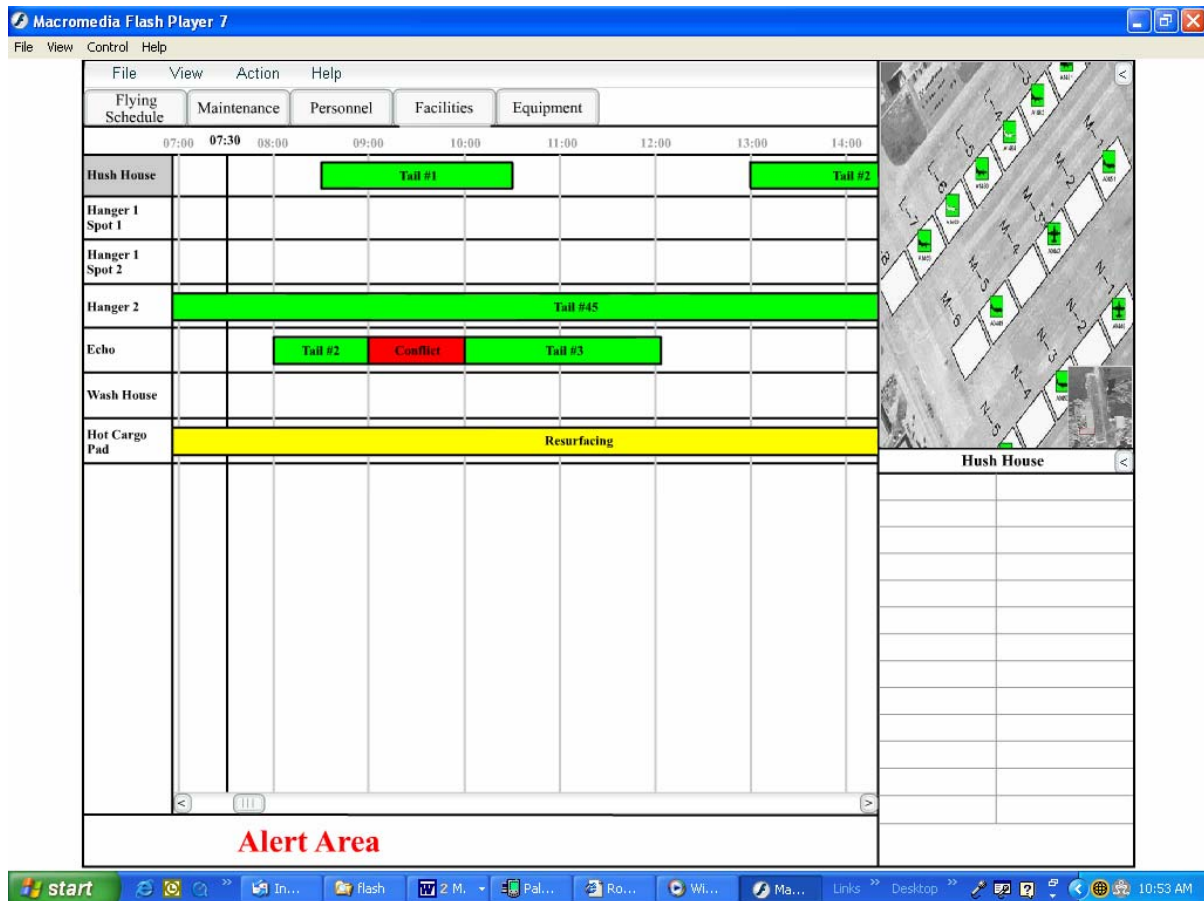


Figure 9. Facilities view concept design

3.4.6 Fleet Health

Our research has shown a need for providing data related to fleet health. Therefore visualization for this data would be important. However, based on time and cost constraints Spiral Three did not focus on these visualizations.

3.4.7 Additional Resources

Expeditors refer to a variety of manuals and resources. The purpose of this function is to provide a place in which to open and view electronic resources that may be needed in the course of the day. Spiral Three did not focus on the design of this functionality.

3.4.8 Collaboration

Expeditors must collaborate with many organizations and individuals. The area below the primary window is a communication area in which the user is able to view messages and alerts. The design concept also includes the functionality of allowing the user to write and send messages. Additionally, automated messages are used to free the user

from having to send messages manually when resources are requested. Collaboration is also enhanced by providing different users with a shared vision. The SSLC2 system can be viewed by Expeditors, the ProSuper, MOC, AGE, and any others who need insight into the maintenance. Each user may have a different view. For example, the ProSuper has access to view all aircraft whereas each Expeditor views the aircraft for which they are responsible. All users see all resources for sharing and awareness of resource use.

3.5 SUBJECT MATTER EXPERT FEEDBACK

The conceptual designs briefly described and illustrated in Adobe Macromedia Flash were presented to four SMEs during a user group meeting. The concepts were explained and SME feedback solicited. In general the SMEs indicated that the concepts were useful and felt that we should proceed to detailed design on the concepts presented. They also provided additional useful information which is summarized in Table 3.

Table 3. Feedback from SME User Group Meeting
Flying Schedule and specific aircraft information

Modifications on configurations (Specific details).
Frag list with load plan.
Pilot crew names to show VIPs and commanders.
Exceptional Releases – prior to flight. Add to line of schedule instead of inspect. (Also known as crew ready. Use crew ready instead of exceptional release.
Could also add de-icing on the time line.
Static displays (aircraft) on the flight schedule used for training (e.g. practice loading) or to show visitors.
Maintenance
When changing ETIC on the maintenance tasks, do not change it on the flying schedule. Don't want to keep bumping ETIC all the time.
In-process inspections should be identified in tasks and reminded.
Equipment
Show what task the equipment is assigned to along with scheduled time of usage.
Show what shop the equipment belongs to (who owns it).
Personnel
Manning number (5 digit unique ID for each person).
Allow the assignment of tasks under personnel, then automatic feedback to maintenance screen.
Facilities
Show who specifically scheduled the use of the facility.

General
Want to see original flying schedule as contracted to be able to show differences to what was contracted versus what was changed.
2407 schedule change- line swap or drop a line must request a change to schedule using 2407 form.
Need another tab for discrepancies based on aircraft. All discrepancies not just those being fixed now.
Must identify who made changes if they are made by other team members.
Add to specifications, how to use history data.
Checklists are needed. (This would be available under additional resources)

3.6 SIMULATION TEST BED

3.6.1 User Interface

After review of the conceptual design with SMEs, the next step was detailed design. The SSLC2 user interface detail design required specifying navigation, specific information on each screen, icons, color usage, redundant coding, error messages, etc. This detailed design information was written into Use Cases and a simulation test bed was then programmed. Of the twenty-two (22) use cases designed, sixteen (16) were fully implemented and one (1) was partially implemented.

The results from the cluster analysis were used to map the specific data elements to the interface. The Table in Appendix B, Data Elements, shows the mapping of the specific data elements described in Section 3.1 to their placement in the interface.

Based on time and cost constraints it was not possible to include all functionality specified in the conceptual design and Use Cases in the simulation test bed. Also, some functionality of the simulated interface was designed in a way that was easiest to program. For example, dialog boxes were used for most data manipulation although a more direct drag and drop interface was originally conceived and should be considered as a requirement in future system updates. The 2407 form used to make an aircraft schedule change, was also not implemented, yet the approval process functionality was implemented. The functionality of zooming, sorting, and filtering were not provided in this Spiral but are considered critical requirements. For this Spiral, the system required scrolling. Although not all functionality was available, the simulation test bed design was such that the users were able to understand the design concepts and functionality and

interact with the system to provide feedback for future design refinement and specification of requirements. Live system interfaces were also not feasible, so data was extracted from these systems and populated into SSLC2.

3.6.2 Simulation Test System Development

The purpose of the simulation test system was to provide the ability to test as well as demonstrate SSLC2 concepts. This section briefly details the overall software architecture followed by more detailed information including software reuse from Spiral One, Spiral One feedback, use case specifications, requirements and model traceability, activity and/or design model, algorithms and business logic, flash prototype and database.

3.6.2.1 Software Architecture

SSLC2 is a three-tier thin client web application. The client tier is a thin client web application that incorporates the GUI. The only commercial software requirement for the client machine is Microsoft Internet Explorer version 5 or greater and a Java Virtual Machine version 1.4 or greater. All the GUI objects are downloaded to the client the first time the computer accesses SSLC2. Subsequent client requests result in download of data only. This design reduces the bandwidth requirements and provides a responsive system.

The middle tier, the business logic of SSLC2, is comprised of servlets currently developed and hosted on Apache Tomcat version 5.5; however, SSLC2 could be rehosted to run on any web server that supports Java server pages, servlets and applets.

Communication to the 3rd tier, the database, is via industry standard Java Database Connectivity (JDBC) protocol. The database used is Oracle version 9i and can be hosted on the same server as the middle tier web server or on a separate server.

The only other software interface created in Spiral Three was an interface to the WhereNet server which provides the simulated resource location data. The WhereNet server, a separate server from the SSLC2 server, supports communications via HyperText Transport Protocol (HTTP). A server side process was created that subscribes to events on the separate WhereNet server via HTTP, in order to receive location information. This information is retrieved by SSLC2 by pinging the WhereNet Application Programming Interface (API) at a timed interval and then inserted into the SSLC2 database via JDBC.

3.6.2.2 Spiral One Reuse

Capitalizing on the previous SSLC2 Spiral One we were able to produce a thin client web application prototype for the Spiral Three Field Test. This section discusses the major software components of Spiral One reused in SSLC2.

A major reuse of Spiral One work included the WhereNet interface and communication functionality. These elements included: database tables, servlets, data objects, and the communications object used to transmit data to and from the server. Some reuse of portions of the schedule occurred as well; however it was necessary to redesign the framework into a 3-panel layout with links and controls between the 3-panels and use animations for viewing simplification. Additional enhancements to the schedule included increased complexity and detail to include new icons for an improved look and feel. Interview methods were used to collect the detail required by the ProSuper, Expeditor, and MOC. This resulted in researching several legacy systems for required data. Patriot Excalibur (PEX) was the major legacy we used for data mining.

The same geo pane from Spiral One was used but with a new map for the Toledo ANG flight line, hangar, AGE yard, avionics shop, hush house, and engine shop. For the detailed view we reused the basic concepts of display with much improved capability and control of the data. The SSLC2 team reused the concept of Roles and incorporated major improvements in identifying three major users with variability defined rules of access.

The build environment included batch files and Apache Ant build scripts that compiled the source files and created a deployment directory containing the entire web application. This directory was controlled through configuration management process along with a source code control tool called Concurrent Version Systems (CVS). This allowed for a simple “drag-and-drop” development method to deploy updates to the SSLC2 application.

Generally, the decision to reuse Spiral One elements was based on SSLC2 functionality and research requirements. The development approach used the Spiral One basic framework and reintroduced elements meeting SSLC2 needs.

3.6.2.3 Use Case Specifications

A use case describes a sequence of actions a system performs yielding an observable result to a particular actor. A series of use cases were created describing how the

application functions, including business rules, screen requirements, user roles, and access rules. SSLC2 interacts with the Expeditor, Pro Super, and MOC. The use cases describe each use case related to the SSLC2 design model. The realizations are presented through sequence diagrams. A sequence diagram is a structured representation of behavior as a series of sequential steps over time. These sequence diagrams depict the work flow of flightline maintenance, communication and management of elements in cooperation over time of maintenance tasks and schedules. Use cases in general also give a basic description, flow of events, alternative flows, special requirements, preconditions, post conditions and any additional actors. Table 4 lists all the use cases developed for SSLC2 Spiral Three and identified whether each was fully implemented, partially implements, or not implemented and on hold for a future Spiral.

Table 4. Spiral Three Use Cases

Use Case	Fully Implemented	Partially Implemented	Not Implemented
Login	X		
Screen Overview	X		
Aircraft Iconography	X		
Alerts and Communication	X		
Geo View	X		
Sort			X
References			X
Flying Schedule View	X		
Update Aircraft Details	X		
Swap Aircraft	X		
Ops Schedule Discrepancy		X	
List Maintenance Task Overview	X		
Maintenance Subtask View	X		
Maintenance Details	X		
List Equipment View	X		
Update Equipment Details	X		
View Personnel Schedule	X		
Update Personnel Details	X		
List Facilities Schedule	X		
Maintain Facilities Schedule and Details		X	

Use Case	Fully Implemented	Partially Implemented	Not Implemented
Update Facilities Detail		X	
WhereNet Interface for Location of Resources		X	

3.6.2.4 Requirements and Model Traceability

Essential to documenting the SSLC2 requirements is the capability to trace from the source, such as a literature search documents, interviews, previous research efforts, through the use cases to the software components and test cases. The Spiral One Final Report was used along with the statistical cluster analysis results, and other decision support research to create visualization and interface requirements as input into the use cases. Use case specifications were developed from these requirements and linked to specific software components and then test cases.

3.6.2.5 Activity and/or Design Model

For Spiral Three, SSLC2 begins when a problem is already identified, assessed and verified. Task steps for fixing or swapping the aircraft and times and types of resources are known and in the system. SSLC2 assigns resources to the problem aircraft based on business rules related to priority, proximity, availability, certification, and ownership. Using SSLC2 the Expeditor monitors the flightline and is alerted when a problem is encountered by the system. The message or alert is detailed in what the problem is and along with task, tail number and resource affected. The Expeditor's first step is to make a choice in how to view the problem through the applications multiple views. He can view information through the flying schedule view, the maintenance views, the equipment views, the personnel views, the geo view, or the facility view. The Expeditor reviews the resources assigned by SSLC2 for maintenance tasks and both the fix and the swap solutions. The Expeditor can override recommendations, select any additional resources or manipulate times based on experience.

The scenario concludes with the Expeditor selecting a course of action. His options are to fix or swap the aircraft or delay or cancel the sortie. If fix is selected, the SSLC2 concept is to automatically notify resource managers, technicians, and inform the ProSuper and MOC. If a swap is selected, it is considered a recommendation that goes to the ProSuper for approval. The final option is to recommend delay or cancel. This also

becomes a recommendation to the ProSuper who in turn negotiates a course of action with Operations. In SSLC2, the problem information as well as the potential solutions would be presented to the ProSuper to facilitate the negotiations.

The User Interface contains 50 screens which includes both primary and secondary screens. Filter and Sort abilities were included in most of the screens for viewing ease. Animations were performed using applets with the communication link to a servlet on the SSLC2 Server through port 80.

3.6.2.6 Algorithms and Business Logic

The SSLC2 simulation uses numerous algorithms to determine resource availability, resource selection, and which aircraft to swap. The logic for these algorithms is described below.

1. Resource Availability – The specific location of resources was specified in WhereNet. In this system it is possible to define zone labels within the RTLS coverage area. The zone information is encoded within the RFID tag and sent in the message to SSLC2. Zones were defined for the entire flightline, each parking location, AGE yard, ready lines, etc. In order for SSLC2 to consider a resource as being available and therefore recommended, it had to be FMC, equivalent to the resource it is replacing, and in any available zone. Resources in any other location were available to be manually selected.
2. Candidate Swap Aircraft – SSLC2 not only recommends resources to meet a fix requirement but also recommends resources to meet a tail swap requirement. One of the resources needed is a candidate tail for the swap. SSLC2 used the following logic:
 - If there is an aircraft designated as a spare, in the same configuration and on the flying schedule then that is the candidate swap;
 - If there is not a spare designated, the candidate tail is the last flyer on that day with the same configuration; or
 - If no other flyers are available, then select an FMC aircraft.

3. System and Automated Alerts – Multiple algorithms were included related to suggestive alerts on issues and problems related to resource changes, aircraft swaps, and ETICs.
4. Resource availability – Multiple algorithms were included to compute resource availability, equivalency, schedule availability, certification matches, and organization approvals.

3.6.2.7 Database

Some of the database design was inherited as a bi-product of reuse of Spiral One. There were some significant changes from Spiral One in order to accommodate Spiral Three's complexity and design. Changes included design elements such as Roles and User tables, storing very detailed equipment/personnel information, aircraft problems and configurations, and organizations that relate to the fix or swap decision. The aircraft problem requirement generated the need to be able to associate tasks, locations, resource details, organization, availability and times to both the fix and swap options.

The roles concept equates to a specific set of software capabilities that are available to different types of users. The capabilities relate to the types of views the user is able to access and also authorization related to approval.

The Spiral One database was designed to handle simple relationships between aircraft, equipment, personnel, and maintenance tasks. Spiral Three expanded on this concept by adding very detailed information which emulated legacy information available in such systems as Patriot Excaliber, CAMS, and G081.

4 Scientific Study Approach

Spiral Three was originally scheduled to include a research study to obtain objective user performance as well as subjective opinions on the use of enhanced sensors fused with information from the flightline to support maintenance tasks, collaboration and decisions. However, due to budgeting constraints the scientific study was redesigned as a field demonstration at one location. This section describes the approach for the field demonstration.

4.1 OBJECTIVE

The objective of this study was to demonstrate SSLC2 and receive feedback on concepts for using smart sensing technologies fused with flightline information to provide work and decision making support to Expeditors and ProSupers in order to enhance resource utilization and maintenance decisions for sortie production. The purpose of SSLC2 is to fuse data from smart sensors, such as RFID/RTLS, with current flightline information and to provide an interactive tool that presents decision quality information to support work performed by flightline personnel. As described in Section 3.0, an interactive simulation test bed was developed to allow maintenance personnel to interact with SSLC2 to monitor maintenance and resources. The simulation was designed to demonstrate different roles, including Expeditor, ProSuper, and MOC. The results of this demonstration provided feedback needed to continue the development of requirements for this type of tool, and provided feedback related to how the data should be fused and presented to support maintenance tasks and decisions.

Two demonstrations were conducted. One demonstration was an interactive simulation with simulated data allowing Expeditors to serve as subjects and interact with the SSLC2 system so they could provide feedback. The second was a demonstration of live tags placed on the flightline. Both demonstrations took place at the same time at the 180th FW Toledo ANG at Toledo Express Airport, Swanton, OH.

4.2 INTERACTIVE SIMULATION

4.2.1 Procedure

Data related to the flightline at the Toledo ANG were obtained which included examples of 14 unscheduled maintenance discrepancies, 7 scheduled maintenance tasks, personnel, equipment, facilities, and a map of the airbase. These data were used to create a simulation using the test bed. The simulation included information related to 17 aircraft with sorties and maintenance for a one week (5 day) period. The simulation begins at the start of the day on Monday. The simulation was divided into four different time periods. Time period 1 began at the start of the day and was used to train subjects on how to interact with the SSLC2 software. The training session took approximately 30 minutes. Following the training session, three additional sessions took place, each for a period of

approximately 10 minutes. Time moves forward at the beginning of each 10 minute session and unscheduled maintenance problems and other resource issues occur. The subjects interacted with the system using a tablet PC with a mouse and keyboard to solve problems, collaborate with other personnel, assign resources, make maintenance and fix/swap decisions, and oversee scheduled and unscheduled maintenance. They received radio calls from an experimenter acting as other flightline personnel to report issues. Table 5 summarizes demonstration elements and events. Simulated data also included RFID tags that provided location and status of resources (personnel and equipment).

Table 5. Example of demonstration elements and simulated events

Session 1: Training 30 Minutes	
What is Being Demonstrated	Events
How to view flying schedule	Change personnel assigned to a mx task
Review of maintenance tasks (scheduled and unscheduled)	Receive a general message
Descriptions of personnel views (make a personnel change)	
Description of equipment view	
Location and status information	
Notifications and requests (collaboration)	Receive request for a person
Sending messages (manual)	
Making changes to a task (edit subtask)	
Understanding how to swap	
Session 2: 10 Minutes	
What is Being Demonstrated	Events
Change in A/C status on schedule view.	A/C 2098 on morning schedule changes status to NMC Nose Wheel problem
Swap	Expeditor notified that a/c 2151 is crew ready
Milestone markers on schedule view.	Expeditor needs to make a swap
Respond to request for resource.	Expeditor reviews nose wheel mx screens
	Receives approval from ProSuper for swap
Visualization of conflict.	Expeditor responds to a request for a resource from Expeditor 2.
	Expeditor reviews conflict and reassigns resource to remove conflict.
Session 3: 10 Minutes	
What is Being Demonstrated	Events
Current time on tasks in process, marking complete	Notification of landing (mark landing time).

Visualization of overdue subtask	Completion of a subtask, alert sent that time is past due, Expeditor must mark complete.
Request a resource not owned	Extend task time on nose wheel problem, cause ETIC to bust.
View landing times	Need to assign a new resources(s) to different tasks
Alerts	ProSuper assigns a resource causing a conflict that expeditor must solve.
New maintenance tasks have appeared	

Session 4: 10 Minutes	
What is Being Demonstrated	Events
SWAP specified by ProSuper	Aircraft are in process of being turned for afternoon flights
New maintenance tasks have appeared	A/C 2132 on afternoon schedule has unscheduled mx problem
Marking Tasks complete	ProSuper initiates swap with a spare that has different configuration (automatic and manual messages sent).
Assigning resources	2085 came back from am flight broke.
Dealing with conflict	Issues with resources occur on tasks.
Changing an ETIC	Problem on one mx task requires an extension of ETIC. Expeditor requests ETIC change.

During the simulation, subjects were asked to verbalize what they were thinking, what action they were taking, and why. Also, during each 10 minute session the experimenter asked subjects 3 to 4 questions to measure their situation awareness. The experimenter then timed how long it took to answer the question using a watch with a second hand. This technique is known as the Situation Present Assessment Method (SPAM) [2].

During the simulation the subject was responsible for the maintenance activity of eight (8) aircraft. An experimenter was logged on as a ProSuper in order to make changes or create events during the simulation and to send and respond to messages from the subject. Events could be initiated through the software or via the radio.

At the end of the session, the subjects were asked to fill out a subjective electronic questionnaire on a separate laptop computer (See Section 4.2.2)

4.2.2 Questionnaire

The questionnaire was designed to ask questions related to seven (7) categories of information and to obtain some information related to the three Key Performance Parameters (KPPs). The list below indicates the type of question and the number of questions in that category.

- Integration of the information (sensors with flightline maintenance information) (INF) - 3
- Visualizations (VIS) - 5
- Situation Awareness (SA) - 6
- Resource allocation (RA) - 1
- Resource visibility (RV) - 1
- Decision support (DS) - 4
- Collaboration (COL)- 2
- Key Performance Parameters 1, 2 and 3. (One KPP was also categorized under DS.)

Subjects were asked to rate the effectiveness of SSLC2 on the six-point rating scale shown below:

- 1 – Not at all effective
- 2 – Not Effective
- 3 – Somewhat Not Effective
- 4 – Somewhat Effective
- 5 – Effective
- 6 – Extremely Effective

In addition to the rating questions, demographic information was collected related to subject's maintenance experience. Two open-ended questions were asked at the end of the questionnaire to obtain suggestions related to additional information that should be included and suggestions for additional sensed information.

4.2.3 Equipment

The interactive simulation included the equipment listed in Table 6.

Table 6. Equipment and purpose for interactive simulation

Equipment	Purpose
SSLC2 Server Dell Dimension 4700 Desktop Computer	SSLC2 simulation software
WhereNet Server on a Dell PowerEdge 4005C Desktop Computer	WhereNet used to simulate the RFID tags

Two Toshiba Protégé 3500 Tablet PC computers	One used by subjects to interact with SSLC2, one used by experimenter acting as ProSuper to respond to subject.
Dell Inspiron 8500 Laptop computer	Data collection to record verbal responses.
Gateway 600 Laptop computer	Electronic questionnaire
Radios	To allow communication from experimenter acting as ProSuper to subject (Expeditor)
Passive monitor	To allow experimenter acting as ProSuper in separate room to hear what was taking place in room with the subject.

4.2.4 SSLC2 Team Members

The simulation required four SSLC2 team members. One experimenter sat with the subject, trained them and asked the situation awareness questions. An experimenter acting as a data recorder also sat in the room with the subject and recorded the verbal protocol on a laptop. A third experimenter was located in the next room and acted as the ProSuper and other personnel on the flightline as needed if the subject called someone. This experimenter also initiated events by using the SSLC2 software. A fourth person controlled the SSLC2 server to update the data at the beginning of each session.

4.2.5 Subjects

Five subjects from Toledo ANG served as subjects. The average number of years they have worked in flightline maintenance was 22.4 with a minimum of 16 and a maximum of 30. Four of the subjects were experienced as Expeditors with an average number of years of 4.35. Two subjects had experience as ProSupers with an average number of years of 4.5; one subject was a maintenance controller. All subjects were male.

4.3 LIVE TAG DEMONSTRATION

The purpose of this demonstration was to illustrate how live sensors and flightline information are integrated to support flightline maintenance and to discuss any questions that personnel on the flightline might have. The simulation created for the interactive demonstration was included to show various aspects of the interface. Additionally 49 RFID tags were placed on Toledo ANG resources. Personnel who had time to visit the demonstration were asked to fill out a short questionnaire if they had time. Only four personnel were able to fill out the questionnaire. The demonstration took place at the same time as the interactive simulation in a separate room.

4.3.1 Equipment

Table 7 summarizes the equipment used for this demonstration.

Table 7. Equipment and purpose for Live Tag demonstration

Equipment	Purpose
SSLC2 Server Dell Dimension 4700 Desktop Computer	SSLC2 simulation software
WhereNet Server on a PowerEdge 4005C Desktop Computer	WhereNet used to simulate the RFID tags (Same server used for interactive demo) Collects data from tags.
Two Toshiba Protégé 3500 Tablet PC Computers	Used demonstrate Expedito and ProSuper roles and visualizations.
Whereports and location sensors *	To pick up sensor signals
49 RFID Tags	Attached to resources across the flightline
Radios	To allow communication to flightline personnel to move resources
InFocus LP640 LCD projector	Project images from tablet pc on wall to allow multiple people to view the demonstration

5 Results and Discussion

This section describes the questionnaire results from the interactive simulation and user comments, comfort ratings, situation awareness probes, questionnaire results from live tag demonstration, followed by a discussion of the study results and a summary of how Spiral Three Objectives were met.

5.1 INTERACTIVE SIMULATION RESULTS

5.1.1 Questionnaire Results

As indicated previously, the questions were categorized into seven areas. Results of mean rating effectiveness are presented by categories below. Following each graph are the subjects comments related to the questions shown in the graphs.

5.1.1.1 Integration of Information (INF)

Figure 10 presents the mean rating of effectiveness for three questions related to integration of information. Subjects indicated that the integration of data and sensor information and information detail was effective. Information organization nearly reached the average effective ($X = 4.6$). Comments indicate that the inability to demonstrate zoom affected their ratings, although it was explained to subjects that zooming is a requirement and would be available in an actual system.

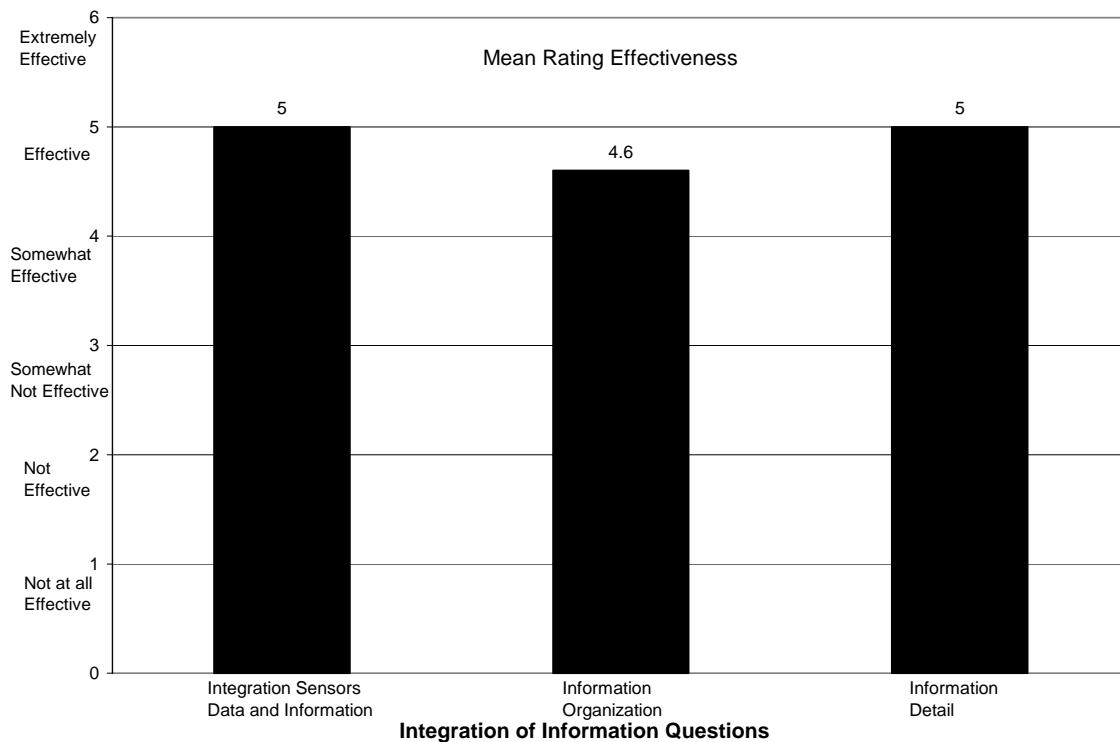


Figure 10. Mean effectiveness rating for questions related to integration of information

Subject Comments by Question:

The integration of information from sensors (status, location) with flightline information (i.e. flight schedules, maintenance, resources) is:

- “Getting Familiar with where to go is key.”
- “From a maintenance management perspective, it's nice to "see" where your people and resources are.”

The way in which the information is organized in SSLC2 is:

- “I like the amount of information available. Again, getting familiar is key.”
- “Need to have the ability to sort work sections”
- “Tasks in the screens were very busy, probably will ‘be’ fixed when you can zoom the screens in and out”
- “Usable. It's good that I could change between the different screens (large to small, small to large).”

The level of information detail presented is: “Very good.”

- “Very good. I was able to find people assigned to tasks and ensure they weren't assigned to two tasks at the same time.”

5.1.1.2 Visualization

Figure 11 presents the mean rating effectiveness for questions related to the visualizations. In general, the subjects found the visualizations to be effective. The rating for overall effectiveness is close to 5.0. Comments related to the flying schedule indicated that ratings were affected by the lack of zooming capability which was an expected outcome. For alerts and notifications, there was no audible alarm to direct their attention so subjects did not always see the messages.

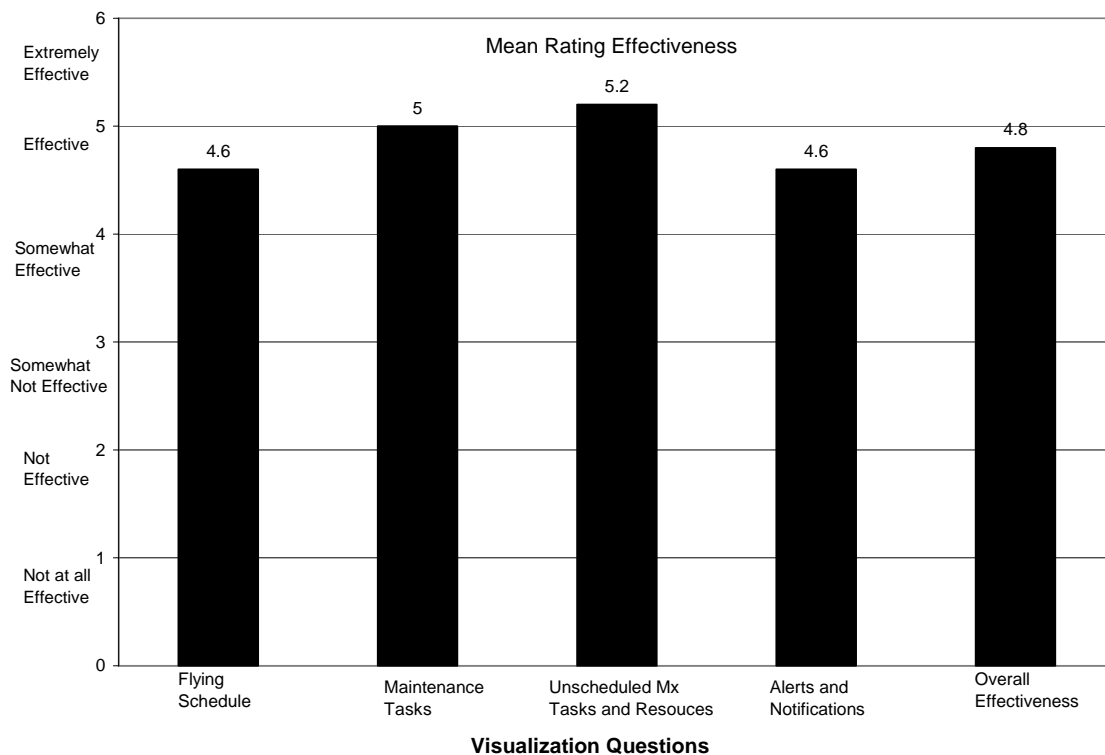


Figure 11. Mean effectiveness rating for visualization questions

Subject Comments by Question:

The visualization of information in the flying schedule is:

- “Good”
- “Need to be able to see more at one time. Should be fixed with the zoom.”
- “Again, would have liked the zoom feature, got lost in the flying schedule window by scrolling forward or back.”
- “But, I should be able to view all of the flyers at once, without scrolling down.”

The visualization of unscheduled and scheduled maintenance task list is:

- “I thought this was an area where you have a lot of information available.”
- “Would've liked to see more of the upcoming hourly/calendar inspections or maintenance on the Maintenance page.

The visualization of unscheduled maintenance subtasks and resources required is:

- “I thought this was an area where you have a lot of information available.”

The visualization of alerts and notifications is:

- “It took me a while to get used to looking for the alerts and responding to them.”
- “Would rather hear a radio call. As an expediter you need to drive and look at what's going on. If it is a general message then it could be sent with maybe a sound notification to let you know you have a message.”
- “The alerts and notifications should have an audible sound to alert me to look at the bottom.”

Subject comments related to Overall effectiveness:

- “I enjoyed interacting with this system and don't think it would take much to operate.”

5.1.1.3 Situation Awareness

Figure 12 presents results for questions related to situation awareness. In general subjects indicated the system was effective for situation awareness, but closer to “somewhat effective” for alerts and notifications. This was related to the fact that the system did not provide an audible alert to indicate a message was presented. Users had to check the messages which were shown at the bottom of the interface.

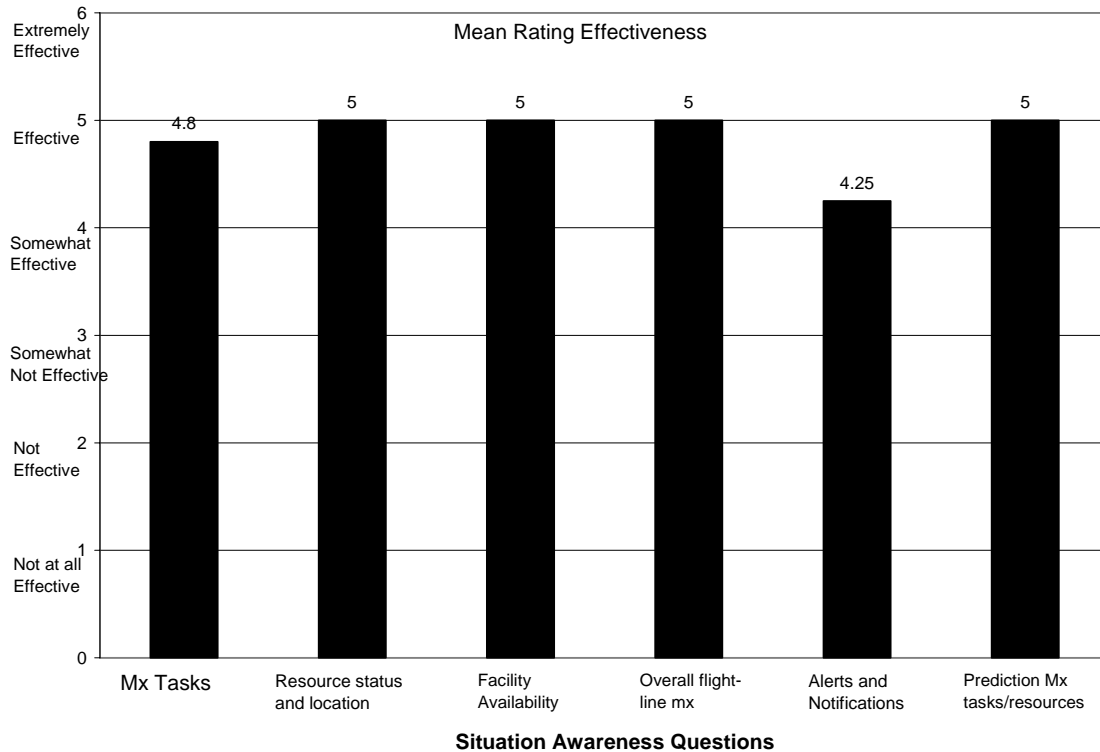


Figure 12. Mean effectiveness rating for situation awareness questions

Subject Comments by Question:

For providing situation awareness of maintenance tasks and subtasks SSLC2 is:

- “I had the most problems with. I continually forgot to click on the subtasks.”
- “It's ideal for seeing the flow of maintenance actions required”

For providing situation awareness of resource (personnel, equipment, and facilities) status and locations SSLC2 is:

- “This was good and the amount of resources loaded into the SSLC2 is effective.”
- “Knowing what's available at any given time is excellent.”

For providing situation awareness of facility availability SSLC2 is:

- “I only used this once but was very easy to use.”

For providing situation awareness of the overall flightline maintenance SSLC2 is:

- “The program makes it easy and fast to find the overall awareness of flight line issues.”

For providing situation awareness of maintenance alerts and notifications SSLC2 is:

- “I didn't stay on top of the alerts but they are easy to see.”
- “Need audible alerts”

For providing information to allow me to predict how changes may affect maintenance tasks and resource use SSLC2 is:

- “I didn't have much interaction with this.”
- “When I extend a maintenance event, the following maintenance events (if any) should automatically be extended by the amount of time that I extended the first event.”

5.1.1.4 Decision Support

Figure 13 presents results for questions related to decision support. Decision support was found to be effective.

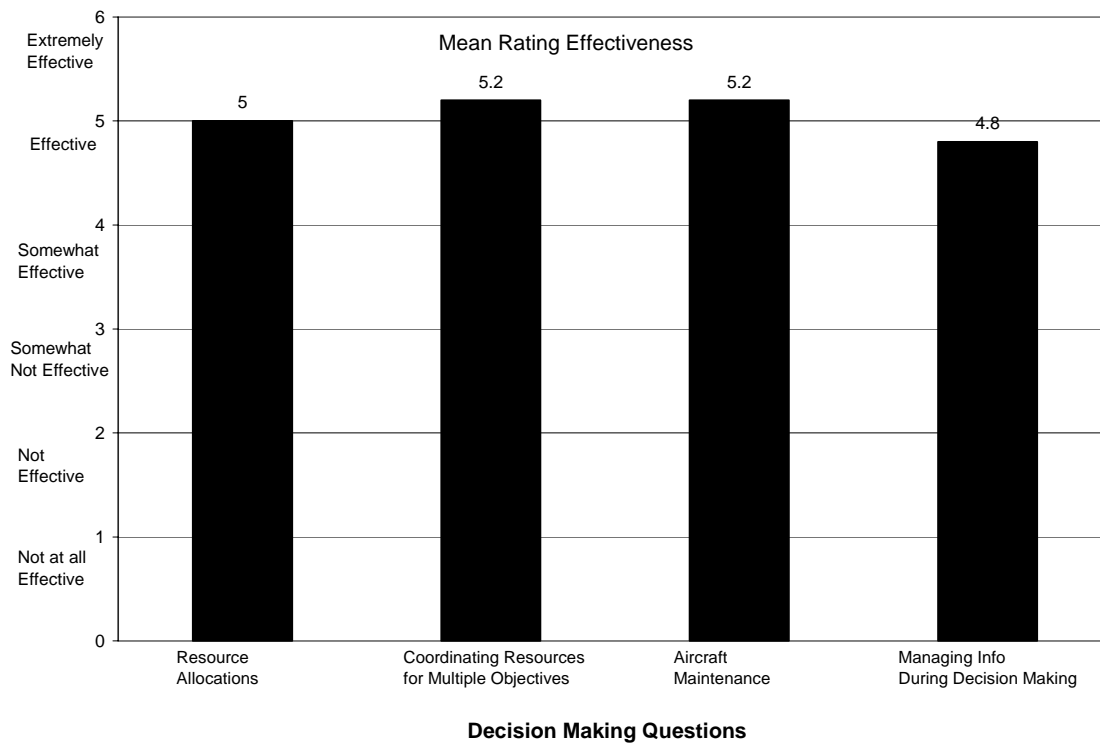


Figure 13. Mean effectiveness rating for decision making questions

Subject Comments by Question:

For supporting my resource allocation decisions SSLC2 is:

- I can't stress enough that getting familiar with the system is key.

For coordinating resources to meet multiple objectives, SSLC2 is:

- “Once I got used to where the resources were located, this was effective”

- “Being able to assign resources to a specific task is very useful”

For supporting my decision making related to aircraft maintenance tasks SSLC2 is:

- “Good”
- “It is very effective to see all personnel that are available to work aircraft maintenance”

For managing information needed during decision making, SSLC2 is:

- “The system gave me all the tools I needed and in the short amount of time I worked with it, it was easy to use.”

5.1.1.5 Collaboration, Resource Visibility, Resource Allocation

Figure 14 shows the mean effectiveness rating for the three categories of questions related to collaboration, resource visibility, and resource allocation. Enhancing collaboration among flightline personnel was rated between “somewhat effective” and “effective”. One comment indicated that it would depend on whether people are working on tasks they are assigned. No one discussed the concept that the system would automatically notify other personnel of a request. They seem to focus on collaboration through the use of messages and as indicated in previous comments, no audible sound was given when a message appeared.

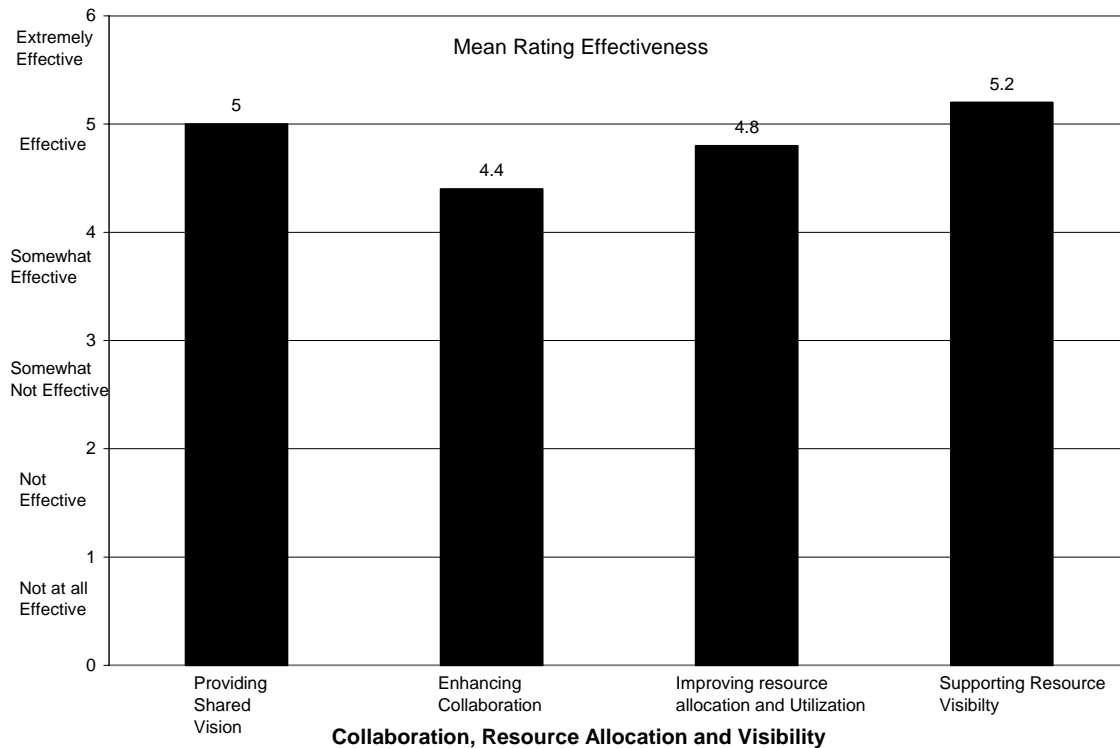


Figure 14. Mean effectiveness rating for collaboration, resource allocation and resource visibility questions

Subject Comments by Question:

For providing a shared vision of what is occurring on the flightline, SSLC2 is:

- “With the SSLC2 available to all supervisors, this makes visual mgt easy.”
- “Didn't care for having to scroll through the aircraft, would prefer being able to see all of the jets at once.”

For enhancing collaboration among flightline personnel SSLC2 is:

- “Effective as long as personnel are doing what they are assigned to do.”

For improving resource allocation and utilization (above current levels), SSLC2 is:

- “I feel this can improve resource allocation.”

For supporting resource visibility, SSLC2 is:

- No subjects provided comments

5.1.1.6 Key Performance Parameters

Figure 15 provides mean effectiveness ratings for three questions that were related to key performance parameters. KPP1 and KPP2 questions were rated just below

Effective. KPP3, related to reduction in time compared to baseline, was rated between Somewhat Effective and Effective. Because this is a simulated demonstration it is difficult for users to really know how it may affect their performance and time. An in-depth field study where users can work with the software in their current environment is needed to truly evaluate SSLC2 effectiveness.

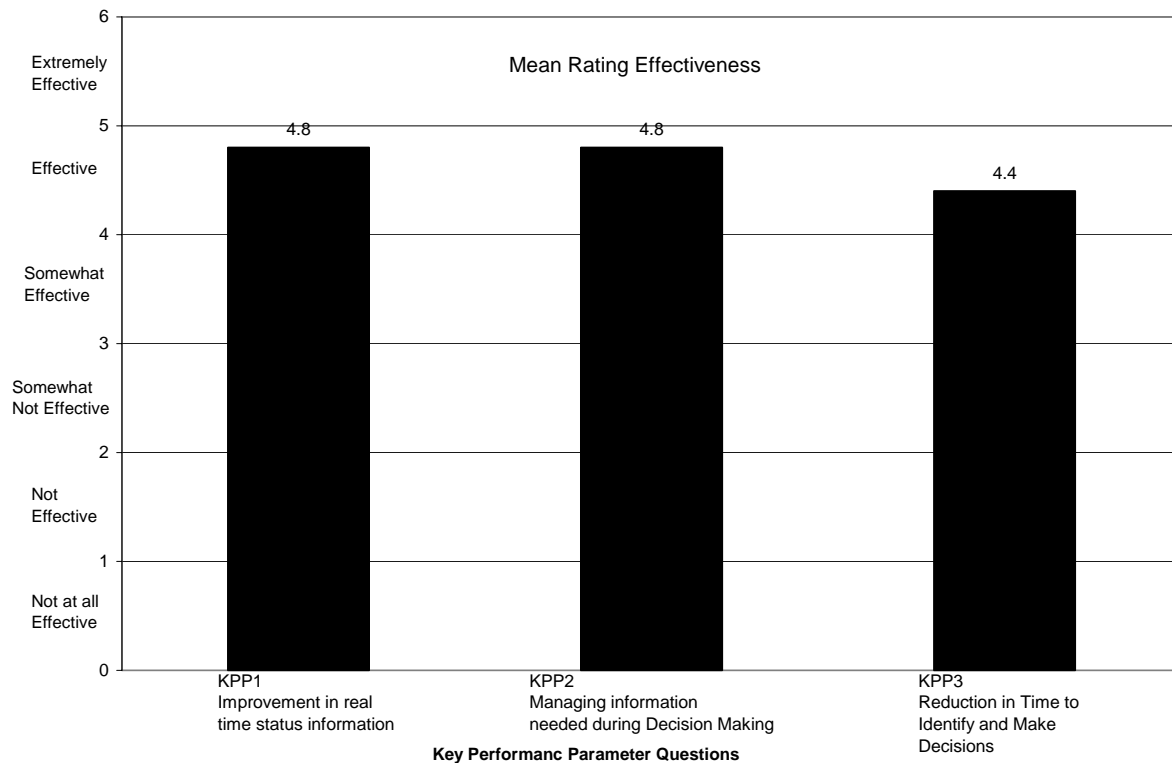


Figure 15. Mean effectiveness rating for questions related to key performance parameters

Subject Comments by Question:

Real time status information provided by SSLC2 as an improvement over current practice is:

- “I like that this is up-dated so quickly.”
- “I can see where a finished product would be a significant advantage but in my limited time in dealing with the software, I think the system needs to be a little more user friendly to become a true asset over current practices.”
- “Knowing where equipment and resources are in real time would be very useful.”

For managing information needed during decision making, SSLC2 is:

- “The system gave me all the tools I needed and in the short amount of time I worked with it, it was easy top use.”

Reduction in time to identify and make decisions with SSLC2 real time information (compared to current practice) is:

- “Not sure if is an improvement to calling a shop directly and requesting someone or something.”
- “Providing the information is updated in real time, it would be very useful in making decisions.”
- “See above comments” (This appears to be referring to the following previous comment: “I can see where a finished product would be a significant advantage but in my limited time in dealing with the software, I think the system needs to be a little more user friendly to become a true asset over current practices.”)

5.1.1.7 Open-ended questions

Two open-ended questions were asked at the end of the questionnaire to obtain suggestions related to additional information that should be included and suggestions for additional sensed information. The comments for these questions are listed below.

Question 1: What additional information would you like to see included in this type of technology?

- “I don't have anything to offer here.”
- “Weekly view for scheduled maintenance. Weekly/Monthly view of the flying plan.”
- “Nothing at this time”
- “Maybe a main status screen including all aircraft, with extremely general info, with links to the maintenance tab and flying schedule.”
- “Keep maintenance functions, maintenance functions; keep flying functions, flying functions. Changing the maintenance ETIC on the flying board is an example of this. ETICs should come from the maintenance tab. My first impression of the program is that it looks very labor intensive. Keep it simple, point and click, dropdown menus, etc.”

Question 2: What additional sensed information would you like to see included in this type of technology? (i.e., additional types of automatic sensors).

- “Same” (referring to: “I don't have anything to offer here.”)
- “Not sure at this time”
- “None at this time”
- “Nothing additional is coming to mind at this time.”

5.1.2 Comfort Ratings

After training and at the end of each 10 minute simulation session, subjects were asked on a scale of 1-10, with 10 being the most comfortable, how comfortable they felt with the interface. Table 8 lists the results for these ratings. In general, subjects indicated that the interface was not difficult to use, but it would take time to become familiar with where all the data were located. These ratings are very good considering that the users were only able to interact with the system over a few hours. This indicates that overall the system was easy to use and learn. A usability test was not conducted because of time and cost limitations.

Table 8. Comfort ratings across subjects

Subject Number	Training Session	Session 1	Session 2	Session 3
1	8	8	8	8
2	7	6.5	6.5	6
3	6.5	7	7	7
4	7	8.5	8.5	8.5
5	6	7	6	Missing data
Mean	6.9	7.4	7.2	7.4 (n=4)

5.1.3 Situation Awareness Probe Results

During the simulation the experimenter would ask the subject a situation awareness probe question. The time to answer the question was recorded. In some cases the questions were not asked or the timing data were not accurately collected. However, the technique did provide some limited insight into their ability to know where to find data. Table 9 lists the probe questions, the mean time to answer and minimum and maximum times. In general subjects were able to find the data within a minute. One subject had difficulty finding the next phase inspection information taking at total of 240 seconds, whereas all other subjects found this data in 30 seconds or less. One subject also had difficulty determining the number of avionics specialist's that were currently assigned to aircraft requiring help but timing data were not correctly recorded.

Table 9. Average time to answer probe questions

Session 1	N	Mean (seconds)	Maximum	Minimum
Where is Crew Chief “name”	4	29	60	15
Where is “name” right now	2	37	25	25
What equipment would be used to do OPS check on 2098?	3	43	60	30
Session 2				
What certification does (person’s name) have?	5	38	50	20
How many EE are currently assigned?	5	48	60	30
When is next phase inspection for a/c “X”	5	66	240	12
Session 3				
What Avionics Specialist is assigned to a/c “X”?	4	42	75	15
Given the maintenance issues you see how will this affect your schedule tomorrow?	4	61	110	13
Total Average		46		

5.2 LIVE DEMONSTRATION

A questionnaire with 11 questions was available for personnel who participated in the live tag demonstration. Four people turned in questionnaires. The results are listed in Table 10, with the number for each question indicating the frequency of the response. The small sample size makes it difficult to draw any specific conclusions; however, the numbers are similar to the questionnaire results for the five subjects who interacted with the system during the interactive simulation. Overall, the subjective impressions are very positive.

The two open-ended questions that were included in the interactive simulation were also included on this survey. The comments for these questions are listed below.

Question 1: What additional information would you like to see included in this type of technology?

- Include Sender in messaging option
- Tool Software Integration

Question 2: What additional sensed information would you like to see included in this type of technology? (i.e., additional types of automatic sensors).

- No comments provided

Table 10. Questionnaire results for the live demonstration

CODE	Statements	Not at all Effective 1	Not Effective 2	Somewhat Not Effective 3	Somewhat Effective 4	Effective 5	Extremely Effective 6
INF	The integration of information from sensors (status, location) with flightline information (i.e., flight schedules, maintenance, resource) is:					4	
DS, KPP2	For managing information needed during decision making, SSLC2 is:				2	1	1
COL	For enhancing collaboration among flightline personnel SSLC2 is				1	3	
RA	For improving resource allocation and utilization (above current levels), SSCL2 is					4	
RV	For supporting resource visibility, SSLC2 is:					3	1
KPP 1	Real time status information provided by SSLC2 as an improvement over current practice is:				2	1	1
KPP3	Reduction in time to identify and make decisions with SSLC2 real time information (compared to current practice) is:				1	3	
VIS	The visualizations of resource status and locations are:					2	2
	Overall, SSLC2 appears to be:					4	

5.3 DISCUSSION

5.3.1 User Performance

The questionnaire results, comfort ratings, and timing results for situation awareness probe questions indicate that overall subjects found the SSLC2 system to be effective and useful. Subjects mentioned that their comfort level was related primarily to the fact that they needed time to practice with the system given the large amount of data available to them. Ratings were sometimes affected by the lack of zoom and filtering functions. For example, comments include the need to view weekly and monthly schedules. With zoom, they would be able to see the schedule at any level, but this was not demonstrated. There was also a general feeling that messages and alerts would require audio tones, however, this must be carefully evaluated based on how many they may receive. Too many messages and alerts could be overwhelming.

It is interesting to note that subjects did not indicate that any information was missing and subjects only occasionally thought data should be located in a different place. Subjects were able to find most information quickly according to the situation awareness probe results. In some cases the experimenter needed to help them find information, however, most subjects indicated that they just needed more time to become familiar with the interface.

One subject requested information related to personnel by work centers. This is due to the fact that filtering was not available during the demonstration, but there is a requirement to sort or filter personnel by work centers.

The use of verbal protocol during the simulation allowed us to understand how users were proceeding through the interface and to determine issues they had. From the verbal protocol and questionnaire results we found that the interface allowed the subjects to quickly see when things on the flightline were beginning to go wrong (i.e. maintenance problems started occurring). If they saw a problem they would determine if that aircraft was flying that day. They would concentrate on aircraft that were flying first. Checking for this information required moving to the flying schedule. To reduce the need to move too often between screens, an indication of the next scheduled flight time for any broken aircraft could be provided on the maintenance screen.

Table 11 indicates issues that occurred during the interactive simulation and some possible solutions based on the existing interface.

Table 11. Issues noticed during interactive simulation and possible solutions

Issue	Possible Solutions
User looking for exceptional release. Realized later that crew ready was exceptional release.	Related to definitions. Can be solved with limited training.
Issue with finding personnel that were in conflict. The maintenance subtask screen indicated a conflict but did not indicate specifically personnel that were in conflict. Requires users to look in mx views and personnel views.	Conflict data should be visible in multiple locations including detail views. The detail view could highlight specific tasks the resource is assigned to that are in conflict.
Not enough information on certifications with just numbers.	Names of certification required rather than just certification numbers.
Some difficulty in finding task end times.	Suggestion for including subtask time in details view when the top bar of the subtask is selected in subtask mx view.
Suggestion for the need for a breakdown of information by work centers.	Subject suggested tabs at top for different work centers when looking at personnel. Filtering requirement solves this problem.
Aircraft ETIC is on flying schedule. Subject considers it maintenance issue so should be on mx screens	Add ETIC to mx subtask details screen.
Difficulty performing swap from the swap dialog box. Selection was difficult at times and the highlighting of sorties was confusing.	Consider redesigning swap function. Drag and drop functionality not included in the test bed would solve this problem.
Subject wants more information on what tasks are coming up in terms of all scheduled inspections.	This information is in the mx view, however, data were only available for one week for the demo. Consider design of screens that provides quick look summary of schedule maintenance up to one month in the schedule.
Subject looked for phase in mx screens.	Phase was in the flying schedule view. Can easily also add to details view under mx screen.
Reassigning personnel to tasks was sometimes confusing.	Consider eliminating the remove/reassign dialog box and use drag and drop functionality. Must consider how to maintain useful conflict checking.
Include the ability to assign a new spare. After a swap is performed using the spare the user may want to assign another aircraft to be an additional spare. This will enable a quick swap decision to be made if required when a launch is pending.	In addition to swap function include reassignment functions.

Issue	Possible Solutions
Identify when an aircraft requiring a certain configuration for a sortie does not currently have that configuration.	Determine best technique to bring to the user's attention that a configuration difference exists.
Ability to quickly see labels for items on the geo view.	Resources on the geo view may be stacked. To identify a specific item labels should be available. Currently if icons are stacked, user must click on the icon and a dialog box with list of equipment appears. Non-stacked icons do not have labels. Techniques to consider are labels appear when cursor hovers, or ability to turn on/off labels.
Automatically extend entire task time when user edits the time of a subtask.	Automatically extending times when subtask was changed was not included in this spiral based on time constraints. This functionality should be included.
When selecting an aircraft on the schedule view, the aircraft details are related only to the next sortie. Include the ability to see details related to any scheduled sorties.	Consider allowing the user to select the line number to show details related to the aircraft for that sortie.
Refresh was slow.	Need to increase refresh speed and determine best configurations for refresh frequencies.

5.3.2 Testimonials

After completion of the field demonstration, SSLC2 team members went back to the Toledo ANG to debrief and obtain any additional comments they may have after having thought about the system. During that time the lead ProSuper discussed his views of the SSLC2 system. He indicated to researchers that currently it takes 15 minutes to collect the information needed to make a decision about whether or not an aircraft will meet a sortie. With this system he stated that they could make that decision in seconds. He also stated the system could reduce the time to make decisions and assign resources to maintenance tasks by up to 60%.

5.3.3 Meeting SSLC2 Spiral Three Objectives

Spiral Three had five objectives as outlined in Section 3.0. This section summarizes the work completed to meet each objective.

Objective 1: Develop smart sensors for logistics operations.

During Spiral Three Alion Science and Technology, Inc. began development of smart tags based on Spiral One field test feedback to provide status information in addition to location information. They developed a smart tag that provided two levels of status

(available/not available, on/off). Due to budgeting constraints the tags were not included in the field demonstration.

The SSLC2 test bed simulated the use of smart tags that provided information about resource status including broken, in use, and available. During the demonstration, flightline maintainers were asked if there was additional sensed information that might be useful. They did not provide any specific suggestions. Recommendations for smart sensors are discussed under 6.0 Recommendations.

Objective 2: Develop a method for determining how data should be fused for presentation that focuses on supporting decisions and collaboration.

When designing interactive visualizations to support human users, a user-centered approach is required. For many complex systems the amount of information and the number of decisions users make during their work can be very large. Mapping the information to the design to support decisions is important, but visualization design is somewhat of an art form. During this spiral we developed a rating technique to allow SMEs to rate the importance of information across decisions and performed a cluster analysis. The cluster analysis was very helpful for developing constraints on how to integrate large amounts of data for arrangement in the interface. This data combined with an understanding of how users perform their work and what information is needed when they are making decisions helped in developing interactive visualizations to support users. While there was limited testing possible in Spiral Three due to resource constraints, the integrated visualizations received more positive comments than did the Spiral One interface. The layout of data was not the primary issue that users mentioned during the simulation. The inability to include the zoom and filtering functionality with this complex interface affected user perceptions even though they were told during training the interface would include zooming and filtering in a future phase. This was not unexpected as it is difficult for the users to conceptualize the functionality. This is another example of how constraints can affect design.

To truly investigate the usefulness of cluster analysis in design, research should be conducted to determine if this technique results in improved interface designs. A study could be developed that provides multiple groups of designers with information to design a user interface. All design teams would receive the same information, but some teams

would also receive cluster analysis results. User interface testing on the resulting designs would help to establish the technique's effectiveness.

Objective 3: Obtain user opinions of deployed sensors in the field.

A field demonstration was conducted to obtain user opinion and performance during a simulated interactive scenario and during a live tag demonstration. The SSLC2 successfully completed this objective. The results indicate that in general SSLC2 concepts are effective.

Objective 4: Develop a simulation test bed and evaluate user feedback on integrated data fusion decision support concepts.

The design concepts were programmed into a simulation test bed as described in Section 3.0 of this report. The SSLC2 team successfully completed this objective.

Objective 5: Develop recommendations for transition to existing systems.

The information gathered during Spiral Three and in the previous Spiral One has provided specific recommendations outlined in Section 6.0 of this report. Additionally, the design concepts described throughout this paper and Use Cases can be considered design recommendations. The SSLC2 team successfully completed this objective.

6 Recommendations

The SSCL2 research conducted during Spirals One and Three has provided a great deal of input toward the design of an interactive decision support system that fuses sensor data with flightline data. The results of this research provide specific requirements for a SSLC2 system. This section provides additional recommendations and future research needs.

6.1 SMART SENSORS

In Spiral One it was recommended that smart sensors be developed that included information in addition to location. In Spiral Three, a smart tag was designed to track personnel location that could also indicate status. Also, smart sensors with status information for equipment and personnel resources were simulated in the field demonstration. Equipment status included broken, in use, and available. Personnel included available or not available. The users found this information useful and chose

personnel for tasks based on their availability. Comments indicated that users like the ability to easily find personnel. Although users were asked if there was any other information they would like sensed, they indicated they could not think of any. Recommendations for additional information that could be sensed and integrated include the following:

- Supplies on the quick reference list;
- Equipment fuel level;
- Liquid oxygen level;
- Temperature;
- Battery level; and
- Oil levels.

The information from sensors that can provide this information could easily be implemented into the visualization interface without major interface changes by providing the information in the details screens. Additional sensed information could be evaluated to determine how and when they would be used so that it can be integrated into the system effectively. Efficient use of sensors and integration of the information is critical and the potential for information overload is very high. It is recommended that information related to critical, Low Density/High Demand (LD/HD) items be sensed.

In addition to the items listed above, smart sensors that can be used to keep track of the aircraft configuration would be very useful. This recommendation is discussed in section 6.6 below, Configuration Tracking.

6.2 USER INTERFACE

The user interface concepts were developed by following a user-centered approach where cognitive task analysis was used as input to the design. The use of cluster analysis to help determine how information should be grouped for design in the interface was a very useful technique and resulted in an interface that was easy to use and allowed a great deal of information to be easily available to the user when needed.

As with any project, there were time and cost constraints which affected some design choices for the test bed. However, the interface still allowed concepts to be presented to users for important feedback. For future research and development of SSLC2, updates to the user interface are recommended and described below.

6.2.1 Portability and Touch Screen Interface

The SSLC2 system requires portability because users are always moving; therefore, the interface should limit the need for a great deal of keyboard entry. The tablet PCs used for the field demonstration did not allow for easy touch screen tapping and a keyboard was needed for input. A mouse was used for input. The use of tablet PCs with handwriting recognition and touch screen interface is important. Newer systems are more advanced as is illustrated by new gaming technology.

6.2.2 Drag and drop

While the overall concept and navigation for the interface was easy and understandable, too many menu interactions and dialog boxes with keyboard inputs were needed. As recommended in Spiral One, the direct manipulation interface should include drag and drop capabilities and users did mention this during the field test. For example, swapping an aircraft required a dialog box. However, dragging the spare aircraft or aircraft to be swapped to the line would be feasible. At that point the system can check for conflicts and if there are any, provide a dialog box that indicates a conflict and asks users if they would like to continue. If this capability is included the user should also have an option to easily see what aircraft are recommended for the swap and what the current configuration is. Another example is editing subtasks which required a dialog box. The ability to use the input device and perform a tap that is similar to a right mouse click could allow the user to edit portions of the subtask directly from the subtask box in the maintenance screen. New concepts for manipulating the data should be designed, explored and tested before implementation.

6.2.3 Tailored Interface

Users indicated they would like to be able to tailor the interface for their use. For example, they would like to tailor the view of the windows to indicate if and when the different views (geo and detail) were available. They may also like to tailor the order of the information in the details screen and be able to turn on or off information in the views. For example, some users would like to have the job control number linked with CAMS in the data, while others do not. Future spirals should consider how the interface can be tailored and test approaches.

6.3 TREND ANALYSIS

During Spiral One it was recommended that SSCL2 have the capability of allowing users to “replay” or review what occurred over a specific time period to enable them to study decisions and impacts for trend analysis and lessons learned. This trend analysis is a continued recommendation and requires study to determine the best way in which to analyze and present the data in order for it to be useful. Capturing all the history data so the user can go back and either replay the past events or look at the specific history of a specific resource would be very valuable for trend analysis and resource allocation decisions. Smart Systems could provide a review of what occurred over a previous time period including changes to schedules, resources, and their status.

6.4 FLIGHTLINE PERFORMANCE METRICS

Flightline performance metrics for establishing fleet health are an important part of flightline maintenance and should be included as part of SSLC2. Spiral Three did not focus on this requirement; however, as indicated in the conceptual design the system could include performance metrics on a separate tab. While not included in the Spiral Three conceptual design the following information was collected which should be considered for monitoring and assessing fleet health for future spirals. This list includes performance metrics currently defined in Air Force documents as well as other data that could be considered part of trend analysis.

- Identify equipment resources trends, for example equipment that are down for specified periods of time (day, or days).
- Specify trends for usage of facilities over past week, month. Specify when facilities were not available or in use when needed (i.e. conflicts that arose).
- Specify NMC rate over past week, month.
- Specify number of times CANN was necessary.
- Specify number of times aircraft swap, delay, cancel, late takeoffs and landings, aborts occurred over past week, month and indications for causes for these flying schedule deviations.
- Show trend data for reasons for flying schedule deviations (lack of personnel, equipment, facilities, supplies, weather, crew delay).
- Specify trends of equipment usage as a function of availability, over time. Indicate when thresholds have been reached.
- Specify equipment failure rates over time (specific equipment and overall equipment).

- Specify overtime rates and utilization rates for work centers over time.
- Identify personnel availability for current week and month including their qualifications, etc.
- Specify the balance of skills over time and what it should be.
- Identify repeat discrepancies.
- Specify general times to perform maintenance tasks against recommended maintenance times. (May indicate training needs).
- Show trends for personnel availability over past month.
- Indicate specific aircraft maintenance trends over time based on discrepancies (recurring malfunction trends).
- Specify aircraft subsystems maintenance trends over time based on discrepancies (recurring malfunction trends).
- Specify systems that are fixed on site vs. depot fix trends.
- Specify supply stock trends.
- Flying schedule effectiveness: (Actual, goal, trend by month).
- Flying schedule deviations (month based on reason).
- Abort rate
- Mission Capable (MC) rate
- Total Not Mission Capable Rate For Maintenance (TNMCM) rate
- CANN rate
- Break rate
- 8 or 12 hr fix rate
- Repair cycle
- Chargeable deviations
- Engine running crew change
- Ground abort (discrepancy after aircrew arrival such that crew can not complete scheduled mission).
- Maintenance non-delivery: sortie cancel due to maintenance.
- Operations non-delivery: late crew show, schedule conflicts for instructor or student; late return from previous sortie, Foreign Object Damage (FOD), etc.
- Supply non-delivery lack of repair parts, fuel, late delivery of service (fuel, oil).
- Deletions: sorties scheduled and not flown.
- Additions: aircraft added to weekly schedule (maintenance and operations).
- Weather Additions
- Weather deletions
- NMC aircraft replacement
- Air abort

6.5 COLLABORATION AND SHARED VISION

Flightline maintenance requires significant collaboration among people and work shops. The ability for users to collaborate and easily view the status of the flightline, including maintenance task requirements and key resources and their status is the key to increasing operational capability and sortie production and to optimizing the use of resources. During the field test demonstration users mentioned how they thought the system would be very useful for other users such as MOC, allowing everyone to know what was going on. Spiral Three included collaboration by including multiple users in the design (ProSuper, MOC, work shops), and by including the ability to send manual messages and to send and received automated messages that affect maintenance and resource use. However, this is just a starting point for possible improvements in collaboration. The system could assist collaboration in additional ways. For example, with the inclusion of data analysis that supports analysis of trends and with the data collection on flightline metrics, the system could create reports for daily, weekly and monthly meetings, similar to Spiral Two, VSLRC [11]. Additionally, smart reports could be generated at various shops and Expeditors and ProSupers providing summaries of resource and maintenance status at the beginning of a shift, thus allowing users a quick glance. They could then move deeper into the system for more specific information.

The ability to send and receive messages via the communication window is another form of collaboration. The current field test included the ability to send manual messages and system generated messages. This function was included for testing based on findings from Spiral One which indicated that some resources need to be shared across Expeditors and also across different maintenance groups when deployed. If a resource is owned by a different maintenance group the Expeditor must call to borrow the resource. SSLC2 lets the user see what equipment are available even across maintenance groups and sends requests automatically.

System generated messages implemented and considered but not implemented are listed in Table 12.

Table 12. Messages and Alerts

Reason for Message or Alert	Implemented Spiral Three?
1. An Expeditor has assigned personnel or equipment, not under his control, to perform a task. Requesting a resource.	YES
2. A supervisor (i.e., ProSuper, Maintenance Supervisor) changes a resource that the user (i.e., Expeditor of a specific aircraft) is in charge of monitoring.	YES
3. A supervisor or another user changed the completion time on a maintenance sub-task. a. Threatens to affect aircraft ETIC b. Threatens entire task completion time but not ETIC c. Does not threaten entire task completion time.	YES
4. A sub-task is delayed (i.e., has not finished within specified time period) and therefore threatens meeting the task completion time a. Threatens to affect aircraft ETIC b. Does not threaten aircraft ETIC.	YES
5. Expeditor or ProSuper changes the ETIC of an aircraft. a. The ProSuper changes the aircraft ETIC and it does not exceed crew ready time. (Notice sent to MOC and Expeditor) b. The ProSuper changes the aircraft ETIC and it does exceed crew ready time. (Notice sent to MOC and Expeditor) c. The Expeditor requests an ETIC change and it exceeds crew ready. (Notice sent to ProSuper) d. The Expeditor requests an ETIC change and it does not exceed crew ready. (Notice sent to ProSuper).	YES
6. A swap is initiated. a. A swap is initiated by the ProSuper b. A swap is initiated by the Expeditor	YES
7. A schedule change has been issued, meaning that a 2407 has been generated. Note: Only a MOC can approve a schedule change (AF-2407) a. Action required b. Notification no action required	NO
8. Approval of an AF-2407	NO
9. In-process inspection required	NO

Additional possible messages/alerts to consider include:

- Alert when a new discrepancy is reported.
- Alert when the aircraft is scheduled to start take-off or landing sequence.
- Alert to highly dangerous/ hazardous maintenance tasks.
- Alert when certain resource levels are reaching a specified limited threshold (e.g. when resources are getting low or are all assigned for a specific time period).
- Alert when resource is needed but conflict exists.

Alerting can be used as decision support. For example, decision support systems for prescribing medicines rely specifically on alerts for indicating specific drug interactions and information to pharmacists and physicians. However, a drawback to alerting is that the users can become overwhelmed with too many alerts resulting in alert fatigue. Therefore it is important to determine messages and alerts that should be included in the system and also additional ways in which to provide the information to users.

Users in the field study indicated that they needed an audio alert to let them know when a message arrived. This is possible, but needs to be considered with the fact that they are often in a high noise environment. Some alerts may need audio while others of lower importance might not have audio. If an alert is very serious the alert can also be displayed on top of their working window.

6.6 CONFIGURATION TRACKING

Configuration of the aircraft is very important information for assigning aircraft to sorties and keeping track of maintenance subtasks that require re-configuration or that require the downloading of weapons before maintenance can take place. SMEs indicated that tracking and control of configurations is currently difficult and time consuming. An aircraft's configuration is currently identified on the operational schedule. The configuration consists of information related to Tanks/Pods, Under-wing storage, Missiles, Guns, and AMD/Fuses. SSCL2 could be used to help users to track and control configurations. There are several possibilities for including this in SSCL2. One would be to include a function that allowed the user to input changes to the configurations to update the SSCL2 data. Another future possibility is the use of sensors on the aircraft equipment. Thus, the configuration can be automatically sensed and provided to the system. This is feasible but will require research related to the use of active or passive sensors on the aircraft or weapon rails. It may be that passive systems in which the user scans the information (e.g. bar codes) rather than active tags that radiate information could be used. Future aircraft are being designed to provide information about their on-board systems automatically to provide maintenance information. Information about configuration could also be included.

6.7 INTERFACING WITH EXISTING SYSTEMS

Flightline maintainers do not want or need another stand alone system. SSLC2 requirements are being written so that the functions can be incorporated into another system such as Enhanced Maintenance Operation Center (EMOC) or Expeditionary Combat Support Systems (ECSS). It will be important for SSLC2 to interface with other systems including Core Automated Maintenance System (CAMS), and scheduling tools. For example, the interface with CAMS would save a great deal of time in closing out a job. When the user selects the completion flag on the last subtask of the maintenance task, a message could be sent to CAMS to close that job control number. Currently they must go back into the hangar, log onto CAMS and close out the job.

Users from the field demonstration at Toledo ANG and the data collection trip at Seymour Johnson Air Force Base suggested that SSLC2 integrate with the Tool Accountability Systems (TAS). TAS is used to track tools, test equipment and vehicles. TAS requires users to scan in their personal identifier and then scan in the tool tag and aircraft. These systems could be linked so that smart tags for personnel could link with the TAS tags so that when a person selects an item the system would immediately link the item to the person to connect the two identifiers. If an item was separated from the individual, SSLC2 could quickly be queried to identify the location of the item. This would eliminate the need for scanning and personnel would not have to hang the item identifier on their key chain with their personal identifier.

The SSLC2 research focused on what users would see given available data. It will be critical to determine what data will be available from existing systems and what data will require manual input.

6.8 SAFETY DRIVEN TASKS

There are some aircraft maintenance tasks that are driven by safety. For example, there may be Time Change Technical Orders (TCTO) or Time Change Items (TCI) which require specific maintenance on one or all aircraft. These orders should be included in SSLC2. Originally it was considered to put this data in the aircraft details view. However it may also need to be considered for a maintenance view. This information and how it is presented should be considered in future spirals.

6.9 FORM 2407 ROUTING

The users identified the need to electronically complete, submit, route, and approve the Form 2407 (change of schedule). SSLC2 should provide the ability to submit an electronic version of the Form 2407 for changes made to the flying schedule related to takeoff time delays as well as aircraft swaps. Once the electronic version of the form is submitted, the user's display is updated with the changes, but will signify that the change is not yet approved. The electronic form is sent automatically to all associated parties for approval/acknowledgement. Once all parties that are required to approve the change have approved it, the schedule will change to signify that the changes have been accepted. This functionality was considered for Spiral Three but not fully implemented based on time and cost constraints. The 2407 Form was not routed and completed, but Spiral Three did provide the logic for submitting requests for swap approval and displaying the schedule change as soon as the swap was approved electronically.

6.10 VISUALIZING AND CLEARING CONFLICTS

SSLC2 allowed users to visualize conflicts on the maintenance view, personnel view, and equipment view. With the concepts of zoomable user interfaces it should be easy for users to quickly see conflicts. However, it is possible that they may not see the conflict depending on where they are in a view. For example, they may be zoomed into a specific aircraft maintenance task. There may be a need for additional ways to notify the user of conflicts; however, this need requires confirmation once zooming is available. Alerting is one possibility. Another is to create a high level tab that summarizes conflict, or creating a tab in the details view. Once a conflict is noticed, the user should be able to deal with the conflict at the point in the interface where it is noticed. Currently they have to navigate to the task and use edit subtask.

6.11 FUTURE RESEARCH

6.11.1 Collaboration

Complex systems such as flightline maintenance require significant collaboration. There is considerable need for research related to collaboration in general, and continued need for research related to collaboration specifically for flightline maintenance. For example, how would the use of SSLC2 concepts change the way users communicate with

one another. Do users feel that the system provides them with better awareness such that large amounts of radio communication are not needed? How might Voice Over Internet Protocol (VoIP) be used to reduce radio communications and allow more flightline personnel to communicate? Currently not all personnel carry radios.

Collaboration also occurs during weekly meetings, the ability to automatically create performance reports based on flightline metrics may be beneficial to collaboration allowing everyone to understand what issues exist.

6.11.2 Measuring Decision Making Performance

It is the ultimate goal of SSLC2 and other decision support systems to improve decision making. While conducting this research there were plans to try and measure decision performance. However, this focus was redirected based on cost and time constraints. While there is a large amount of published research in the area of decision making, it is actually very difficult to measure human decision making performance. In many cases the measures are either subjective (questionnaire or user perceptions of their performance) or inferred based on their task performance. One problem is that people can make a good decision that results in a bad outcome, and they can make a bad decision that results in a good outcome. To ensure that decision support systems are making a difference, there is a need for research on objectively measuring complex decision making in field environments.

6.11.3 Automation

Systems such as SSLC2 should consider functions and tasks that can be automated. During this research, alerts and messages were automatically generated based on certain tasks. For example, if the Expeditor assigned a resource to a task and the resource was not owned by the Expeditor, a message was automatically generated requesting the resource. Other tasks could also be automated. For example, if a conflict exists among resources, the system should attempt to deal with the conflict by reassigning. This is feasible because some conflicts arise between high density/low demand resources. For low density, high demand resources the system could recommend changes to fix conflicts by summarizing the information to the user to allow them to make the final choice. For example, the system could determine which aircraft has the next sortie and help the user

choose how to reassign the resource. Another example is if a resource changes status (e.g. resource is broken) the system automatically reassigns another resource.

6.11.4 Smart Sensor Development

As discussed in recommendations above there is still a need for development of sensors that can sense information other than location. Also, sensors used for existing systems could be considered. For example, drivers are told when their gas is low and how many miles until empty. This technology could be incorporated into equipment that requires fuel. Battery sensing indicators could also be used. Research into the use of sensors and their constraints can be directly applied to other complex systems.

7 Conclusions

The goal of SSLC2 Spiral Three was to investigate ways to support logistic decision makers in complex flightline operations through the fusion of existing flightline information with smart sensor information. SSLC2 provides support to Expeditors and ProSupers on the flightline. Spiral Three research focused on the fusion of information and presentation of the information through interactive visualizations to support situation awareness, decision making and collaboration when Expeditors are faced with multiple complex tasks and decisions. The following five research objectives were met:

- Objective 1: Develop smart sensors for logistics operations.
- Objective 2: Develop a method for determining how data should be fused for presentation that focuses on supporting decisions and collaboration.
- Objective 3: Obtain user opinions of deployed sensors in the field.
- Objective 4: Develop a simulation test bed and evaluate user feedback on integrated data fusion decision support concepts.
- Objective 5: Develop recommendations for transition to existing systems

The presentation of information from sensors integrated with flightline information and an understanding of how users perform their work was very successful as demonstrated in both Spiral One [8,10] and Spiral Three. Users were asked to rate the effectiveness of SSLC2 for supporting situation awareness, decision making, collaboration, the effectiveness of information integration, visualizations, resource

visibility and resource allocation. The questionnaire results, comfort ratings, and timing results for situation awareness probe questions indicate that overall subjects found the SSLC2 system to be effective and useful. The user's primary suggestions for improvement were related to functions that are requirements but that were not demonstrated in the simulation due to time and cost constraints such as zooming, sorting, and filtering. Users did not indicate that any information was missing. Users commented that collaboration through messaging would require auditory tones so that they would know when a message was received. The lack of auditory tones led to ratings of "somewhat effective" under collaboration. However, this system also enhances collaboration by letting different personnel and workshops view shared information on resources as well as maintenance tasks and assignments. Users felt that the ability for everyone to see and share the same information was very useful. A ProSuper indicated that there would be considerable time savings for several decisions using SSLC2 including the decision as to whether an aircraft will meet a sortie. He indicated it takes approximately fifteen (15) minutes to collect all the information from various sources to make this decision, but that with SSLC2 the decision could be made in seconds. He also indicated there would be at least a 60% savings in the time it takes to assign/reassign and find all resources needed to fix aircraft.

During Spiral Three, active tags were developed that provide two levels of status information, although not demonstrated due to time and cost constraints, active tags were simulated in the test bed to illustrate how status information, in addition to location information, could improve resource allocation and visibility. Additional information that can be sensed was also described in Section 6 Recommendations.

The simulation test bed approach was very successful, allowing users to interact with SSLC2 to understand the design concepts. The test bed is a functioning hardware and software system that can now be used for further research.

During the design process we created a rating technique to allow SMEs to rate the importance of information across decisions and then performed a cluster analysis. The cluster analysis was very helpful for developing constraints and ideas for integrating large amounts of data for arrangement in the interface.

7.1 CONTRIBUTIONS OF THE RESEARCH

There are many complex systems that can benefit from the use of smart sensors including logistics for air and space, health care, disaster management, homeland security, manufacturing, and industrial processing to name a few. The SSLC2 program demonstrated that commercial off-the-shelf (COTS) applications without thought to integration with existing systems and information is not ideal and can potentially cause more problems or even rejection of the technology. Integration of information is key for the successful use of sensing technologies. This research made the following contributions:

- The research illustrated how cluster analysis techniques can be used to support visualization design by helping to map information to actual decisions. Since visualization design is somewhat of an art form, it is often difficult to move from cognitive work analysis to actual design [9].
- The research identified sensor information in addition to location that would be useful for systems that use equipment and personnel resources to perform work.
- The research illustrated the appropriateness of a user-centered approach to design.
- The research culminated in recommendations and future research concepts that can be applied to other complex systems.
- The research developed designs for interactive visualizations that can be applied to other domains.
- The research documented in-depth details related to the work of Expeditors and ProSupers including decisions they make, information they use, and problems they face.

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Appendix A

Acronyms

Acronyms

Acronym	Definition
ACS	Agile Combat Support
ACWA	Applied Cognitive Work Analysis
AFFOR	Air Force Forces
AFRL/RHAL	Air Force Research Laboratory Logistics Readiness Branch
AFSC	Air Force Specialty Code
AFSPC	Air Force Space Command
AGE	Aerospace Ground Equipment
AIT	Automatic Information Technologies
ALS	Autonomic Logistics System
ANG	Air National Guard
AOC	Air And Space Operations Center
API	Application Programming Interface
ASD	Average Sortie Duration
ATD	Advanced Technology Demonstration
ATO	Air Tasking Order
AV	Avionics Shop
AWP/AWM	Awaiting Parts/Awaiting Materials
BO	Business Objects
CA/CRL	Custodian Authorization/Custody Receipt Listing
CAMS	Core Automated Maintenance System
CANN	Cannibalized
CC	Commander
COL	Collaboration
COTS	Commercial Off-The-Shelf
CR	Crew Ready
CS	Crew Show
CTS	Collaborative Technologies and Systems
CWA	Cognitive Work Analysis
DLL	Dynamic Linked Library
DS	Decision Support
DSRC	Dedicated Short Range Communication
E/E	Electronic And Environmental
ECSS	Expeditionary Combat Support Systems
EE	Electrical Engineering
EMOC	Enhanced Maintenance Operations Center
EMOC	Enhanced Maintenance Operation Center
ENG	Engine Shop
ES	Engine Start
ETIC	Estimated Time Of Completion
EXP	Experimenter
FMC	Fully Mission Capable
FOD	Foreign Object Damage

Acronym	Definition
FSE	Flying Schedule Effectiveness
GEO	Geographic
GPS	Global Positioning System
HTTP	Hypertext Transport Protocol
IDE	Integrated Development Environment
IE	Internet Explorer
IMIS	Integrated Maintenance Information Systems
INF	Integration Of Information
IRA	Interface Requirements Agreements
ITV	In- Transit Visibility
J2EE	Java2 Platform Enterprise Edition
JDBC	Java Database Connectivity
JDK	Java Development Kit
JNDI	Java Naming And Directory Interface
JQS	Job Qualification Standard
JRE	Java Runtime Environment
JSPs	Java Server Pages
JVM	Java Virtual Machine
KPP	Key Performance Parameters
L	Landing
LAN	Local Area Network
LCOM	Logistics Composite Model
LD/HD	Low Density/High Demand
LFD	Last Flight Date
LG	Logistics Group
LOCIS	Library of Congress Information System
MAJCOM	Major Command
MC	Mission Capable
MC	Mission Capable
MDS	Mission Design Series
MES	Mission Essential Subsystem
MESL	Mission Essential Subsystem List
MLS	Main Location Sensor
MOC	Maintenance Operations Center
MX	Maintenance
NIC	Network Interface Card
NMC	Non-Mission Capable
NMC	Non-Mission Capable
OG	Operations Group
OTI	One Time Inspection
PEX	Patriot Excalibur
PFT	Pilot Flight Training
PMC	Partially Mission Capable
ProSupers	Production Supervisors

Acronym	Definition
PS	Prosuper
RA	Resource Allocation
RF	Radio Frequency
RFID/RTLS	Radio Frequency Identification / Real Time Location Systems
RLA	Resource Location Agent
RV	Resource Visibility
SA	Situation Awareness
SID	Oracle System ID
SMC	Missile Systems Center
SMEs	Subject Matter Experts
SPAM	Situation Present Assessment Method
SPARE	Spare
SSLC2	Smart Systems For Logistics Command And Control
STABOPS	Stability Operations
TA/AS	Table of Allowance/Allowance Standard
TAS	Tool Accountability Systems
TCI	Time Change Item
TCI	Time Change Items
TCP/IP	Transmission Control Protocol/Internet Protocol
TCTO	Time Compliance Technical Orders
TCTO	Time Change Technical Orders
TNMCM	Total Not Mission Capable Rate For Maintenance
TO	Take-Off
TOs	Technical Orders
TX	Taxi
UMD	Unit Management Document
UML	Unified Modeling Language
URI	Uniform Resource Identifier
VAL	Vehicle Authorization Listing
VIS	Visualizations
VoIP	Voice Over Internet Protocol
VSLRC	Virtual Space Logistics Readiness Center
WCSS	Work Centered Support Systems
XC	Experimental Cargo
ZUI	Zoomable User Interface

Appendix B

Data Elements

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Introduction

Fusing information from sensors with flightline data to provide shared understanding among personnel, to improve decision making, and to impact logistic operations requires presenting the information in such a way that the user can understand the information and act on it. Development of intuitive interactive visualizations requires a systematic approach that includes a focus on the user, understanding what information is required to make decisions and to enhance effectiveness. The visualizations must integrate information, providing the right information at the right time. While there are general guidelines when developing visualizations, there are no specific rules that are guaranteed to provide useful intuitive visualizations. The most successful visualizations require a user-centered approach which includes a requirements gathering stage to develop a thorough understanding of the information users need, how they perform their work and the decisions they make. This requires performing up front cognitive work analysis to understand what the user needs and transforming the data gathered into actual design of user-interfaces or visualizations.

ProSupers and Expeditors make many decisions requiring significant collaboration among personnel and organizations. Multiple users need access to shared information and it must be provided beyond one day. The user-centered approach included gathering additional information, beyond Spiral One, related to decisions made and information needed for Expeditors and ProSupers by reviewing a variety of flightline documents from multiple U.S. bases, training manuals, and working with SMEs. SMEs included personnel from AFRL Logistics Research Branch as well as discussion with personnel working a real flightline. From this data specific decisions were gathered. The decisions were presented to SMEs who then narrowed down the decisions to thirty-one which can be found in Section 3.3 of the Final Report. In addition to establishing the decisions, information or data elements that are used on the flightline were compiled. A list of 157 different data elements was created.

For input to the design of the visualizations it is important to understand how the data elements map to the decisions. Not all information is needed for each type of decision. The goal was to provide users with easy access to data based on decisions they make.

In order to perform a mapping of what information is needed for different decisions and to determine the importance of information we decided to use a cluster analysis technique. A data matrix was created with the 31 decisions in columns and the 157 data elements in rows. Three SMEs were then asked to read each decision and rate the importance of the 157 data elements to that decision.

The ratings were used as input for the cluster analysis. A hierarchical cluster analysis using Ward's method was conducted within the JMP Professional statistics package (Version 5.0.1.2). The ratings were first averaged across the three SMEs. The cluster analysis was conducted across all decisions to be made. The analysis resulted in 28 clusters of the 157 data items.

This Appendix provides a summary of the cluster results. The table includes a column which provides the average rating of subjects responses across all 31 decisions. The data items were also examined by the average rating for the question of most "important data to be visible most of the time", which is also included in Table 2.

Data Elements

This section details the results of the cluster analysis and the mapping of each data element. Table 1 provides a key to use for linkage to the location of the view or window of the SSLC2 interface. The details screen is always displayed with the specific view. For example, P and P-D will be visible at the same time.

Table 1. User Interface View Keys

Key	View	Key	View
FS	Flying Schedule	F-D	Facilities Detail
FS-D	Flying Schedule Detail	MO	Maintenance Overview
EQ	Equipment	MO-D	Maintenance Overview Detail
EQ-D	Equipment Detail	MS	Maintenance Subtask
P	Personnel	MS-D	Maintenance Subtask Detail
P-D	Personnel Detail	Geo	Geographic view
F	Facilities	Com	Communication window

Table 2 lists all 28 clusters, the data elements included in that cluster, the average rating by SMEs across all decisions per data element, the average rating by the SMEs on whether the data element should be visible most of the time, and the location of that data element on the user interface. The location for information items that were not included

in Spiral Three are left blank, since some items were rated as not at all important. (Less than 2)

Table 2. Data Element Results

Cluster	Data Element	Average rating across all decisions	Average rating “visible info most of the time”	Location on User Interface
1	Tail number (element aircraft)	4.38	5.00	FS, FS-D, MO, MO-D, MS, MS-D, F, Geo
	Status (PMC, NMC, FMC, spare, CANN)	4.06	5.00	FS, FS-D, MO, MO-D, MS, MS-D
	Reason for status	4.23	5.00	FS-D, MO, MO-D, MS, MS-D
	Schedule for day (Current time and date, all aircraft, Status, brief time, take off time, land time duration of flight, load, remarks, turn, weather, Phase?)	4.19	5.00	FS
2	Priority of task	3.95	3.00	FS-D
	ETIC	4.15	5.00	FS, FS-D
	Tasks required to solve problem	4.23	4.33	MS
	Current Discrepancies	4.48	4.33	MS
	Nature of problem.	4.48	5.00	MO, MO-D, MS, MS-D
3	Corrective actions (maintenance)	3.49	3.67	MS
	Discrepancies awaiting parts	3.58	2.67	MS (Notes)
	Scheduled Maintenance	3.57	4.67	MO, MS
	Safety/Danger Considerations (power/hydraulic applications, stress panels removed, aircraft on jacks, weight and balance, etc.)	3.56	3.00	MS (Notes)
	Discrepancies awaiting maintenance	3.38	3.33	MO
4	Personnel current a/c working or task	3.47	2.67	P, P-D, MS, MS-D
	Personnel Availability	3.34	2.67	P, P-D, MS (Edit subtask)
	Supplies on order and expected delivery date	2.10	1.33	
	MICAPS	3.53	3.67	
	Status of backorder parts	3.03	1.00	
5	Availability of critical equipment	2.90	2.00	EQ, EQ-D

Cluster	Data Element	Average rating across all decisions	Average rating “visible info most of the time”	Location on User Interface
	List of CANNED items	2.61	2.33	
	Stage of CANN jet	2.38	2.00	
6	Schedule for the week	2.91	2.33	FS
	Mission Requirements	2.73	2.33	
	Weather forecast	2.70	3.67	Next to communication always visible.
7	Rules for exceptional releases	2.20	1.00	
	Ground Time Requirements	2.19	1.67	
8	Aircraft load	2.19	3.00	FS
	Type of aircraft (Model)	2.49	4.00	FS-D
	Aircraft with pacer motors identified.	2.05	3.67	FS-D
	A/C Projected to be USM	2.47	4.33	
9	Load	2.27	2.67	FS
	Type of sortie on schedules (night, XC, training)	2.48	3.10	FS-D
	MESL (for mission, basic and full)	2.65	1.67	
	Current Configuration	2.89	4.33	FS, FS-D
	Location on flight line	2.84	4.33	FS, FS-D, GEO
10	take-off time	3.31	5.00	FS
	Priority of sorties	3.32	5.00	
11	Schedule changes	3.27	4.33	FS
	Lines required for filling	3.10	4.33	FS
	Service item status, requirement for next flight	3.10	3.67	
12	Land time	2.71	5.00	FS
	Turn	2.55	4.67	FS
	Line number (details type of sortie)	2.55	4.67	FS,FS-D
	A/C Projected to be Spares	2.71	4.33	FS
	A/C Projected to be Prime Flyers	2.71	4.33	FS
13	schedule for the month	1.88	1.67	FS
	Rules for Status Reporting	1.95	1.00	
	Rules for deviation reporting	1.62	1.00	
14	Past week maintenance history	2.33	1.33	
	Scheduling guidelines	2.18	1.00	

Cluster	Data Element	Average rating across all decisions	Average rating “visible info most of the time”	Location on User Interface
	Top Supply Drivers/Parts that have problems	2.42	2.33	
	Work Unit Code	2.42	3.33	MS-D
	Supplies in stock, Inventory levels	3.03	1.00	
	Weight and balance information	1.87	1.00	
15	Crew chief currently assigned	2.47	3.00	FS-D, MO-D, MS-D
	Personnel role (crew chief, specialist, etc)	2.63	3.00	P, PD, FS, MS-D
	Personnel qualifications, certifications	2.74	2.33	P, PD, MS-D
	Qualification Levels (3-level, 5-level, 7-level)	2.81	1.67	P, PD, MS-D
16	Work schedules (shift)	2.03	3.33	P
	Shifts Scheduled	2.39	3.00	P
	Personnel Contact info (name, radio call, or other)	2.11	1.00	P-D
	Personnel Current location	2.22	1.00	P-D, GEO
	AFSC	2.23	2.00	P-D
17	Scheduled Maintenance Requirements (Generic high level used to create yearly forecast - example: average 1 A/C out per month for depot)	2.01	3.33	
	Maintenance Training Requirements	2.20	4.33	
	TCTO (Time Compliance Technical Orders) - Safety Issues - Contains A/C Tail Number, Date	2.77	3.33	FS-D?
	OTI (One Time Inspection) Tail Number, Date	2.76	3.33	FS-D?
	TCI (Time Change Item)	2.69	3.33	FS-D?
18	Last phase inspection	1.55	2.00	FS-D
	Next phase inspection	1.56	2.00	FS-D
	Phase Schedule	1.72	2.00	FS-D
	Engine Hours	1.63	3.00	FS-D
	Airframe flight hours	1.77	2.33	FS-D

Cluster	Data Element	Average rating across all decisions	Average rating “visible info most of the time”	Location on User Interface
	Days/time since last flown (hangar queen)	2.14	3.00	FS-D
	Last flight date (LFD) When aircraft flew last	1.78	3.00	FS-D
19	Facilities available	1.90	1.67	F
	Facilities schedule	1.69	1.67	F
	Facilities needed for maintenance	1.83	1.67	MS, MS-D
20	Equipment Type	1.66	1.00	EQ, EQ-D
	Equip performance capability	1.75	1.00	
	Equip Current status (broke, not broke)	2.03	1.00	EQ, EQ-D
	Equip Availability	2.05	2.33	EQ, EQ-D
	Equip Location	1.90	2.00	EQ-D, GEO
21	crew brief time for aircraft	1.68	2.00	FS
	Passengers	1.78	2.33	FS-D
	Turn Patterns	1.67	4.67	FS
	Cross-County Sorties	1.57	3.33	FS-D
	Night-flying Requirements	1.62	3.33	
	Flybys/Special Activities	1.62	3.33	FS, FS-D
22	Duration of flight	1.45	1.67	FS
	Authorized configurations	1.74	1.33	
	Projected Turn Patterns for each O&M Day	1.84	2.67	
	Squadron Requirements	1.84	1.67	
	Landing codes (0 through 5)	1.87	2.33	
	Diverted aircraft	1.95	3.33	
23	Deviations (type, Code)	1.47	1.67	
	System capability codes (0-8)	1.42	1.00	
	Flight crew for sortie	1.24	2.33	FS-D
	Days and Swings FOD walk times	1.45	2.33	COM
	Quick Reference list	1.65	2.33	
	D-Model Constraints	1.55	2.33	
	Heavy D-model requirement days identified and supported	1.39	2.00	
	Spare D-model allocation	1.49	2.00	

Cluster	Data Element	Average rating across all decisions	Average rating “visible info most of the time”	Location on User Interface
	Heavy pilot flight training (PFT) Days	1.24	2.33	
	Repeat rate	1.52	1.67	MS-D
	Recur rate	1.51	1.67	MS-D
24	Aircraft call sign	1.23	3.00	FS-D
	Assigned facilities (base & unit)	1.32	1.00	F
	Hours to Phase	1.33	1.33	FS-D
	MSE rate	1.41	1.00	
	Operating hours	1.13	1.67	
	Depot Schedule (Tail Number and Target Dates-War time has different rules)	1.18	2.00	
	Depot inputs	1.19	3.00	
	Non-Flying Days	1.31	2.33	FS
25	Leave schedules	1.40	1.33	P
	Training schedules	1.70	2.33	P
	Upcoming personnel Deployments or TDY's	1.56	1.67	P
26	Percentage of time a/c in each state (FMC, PMC, NMC, CANN, hangar queen)	1.87	1.67	
	CANN rate	1.48	1.00	
	8-/12 hour fix rate	1.51	2.00	
	Average deferred/delayed discrepancies per aircraft	1.31	1.00	
	MICAP aircraft part rate	1.44	1.00	
	Average repair cycle days	1.27	1.00	
	Phase flow (time distribution interval)	1.09	1.33	
27	Crew chief assigned past week, or rest of this week or month	1.12	1.00	
	reported fleet average maintenance status	1.14	1.00	
	Over time for the week	1.18	1.00	
	Authorized manning	1.12	1.00	
	Flying hour Allocation	1.10	1.00	

Cluster	Data Element	Average rating across all decisions	Average rating “visible info most of the time”	Location on User Interface
	Position Numbers from Unit Management Document (UMD)	0.96	1.00	
	Table of Allowance/Allowance Standard (TA/AS)	1.00	1.00	
	supply use rates	1.03	0.67	
	Custodian Authorization/Custody Receipt Listing (CA/CRL)	1.02	1.00	
	Vehicle Authorization Listing (VAL)	1.03	1.00	
	Attrition Calculations	1.11	1.00	
	Primary a/c inventory versus possessed aircraft rate	1.09	1.00	
	Chargeable deviation rate	1.22	1.00	
	Nonchargeable deviation rate	1.17	1.00	
	Who owns Equip (this line, or another line or squadron)	1.31	1.00	
	Equip recent and historical utilization rate	1.28	1.00	
	Deployment Plans	1.28	1.00	
	authorized equipment	1.08	1.00	
	Ground Abort rate	1.25	1.33	
	Air abort rate	1.23	1.33	
	Code 3 break rate	1.29	1.33	
	MAF total air abort rate (home station air aborts +J diverts)	1.05	1.00	
	Logistics departure reliability	1.12	1.00	
	Functional check flight release rate	1.14	1.00	
	Issue effectiveness rate	1.12	1.00	
	Stockage effectiveness rate	1.08	1.00	
	Bench stock effectiveness rate	1.10	1.00	
28	Programmed UTE versus actual UTE	1.25	1.00	
	Programmed average sortie duration (ASD) vs actual ASD	1.18	1.00	
	Flying hour execution	1.27	1.00	
	Flying schedule effectiveness rate (FSE rate)	1.22	1.00	